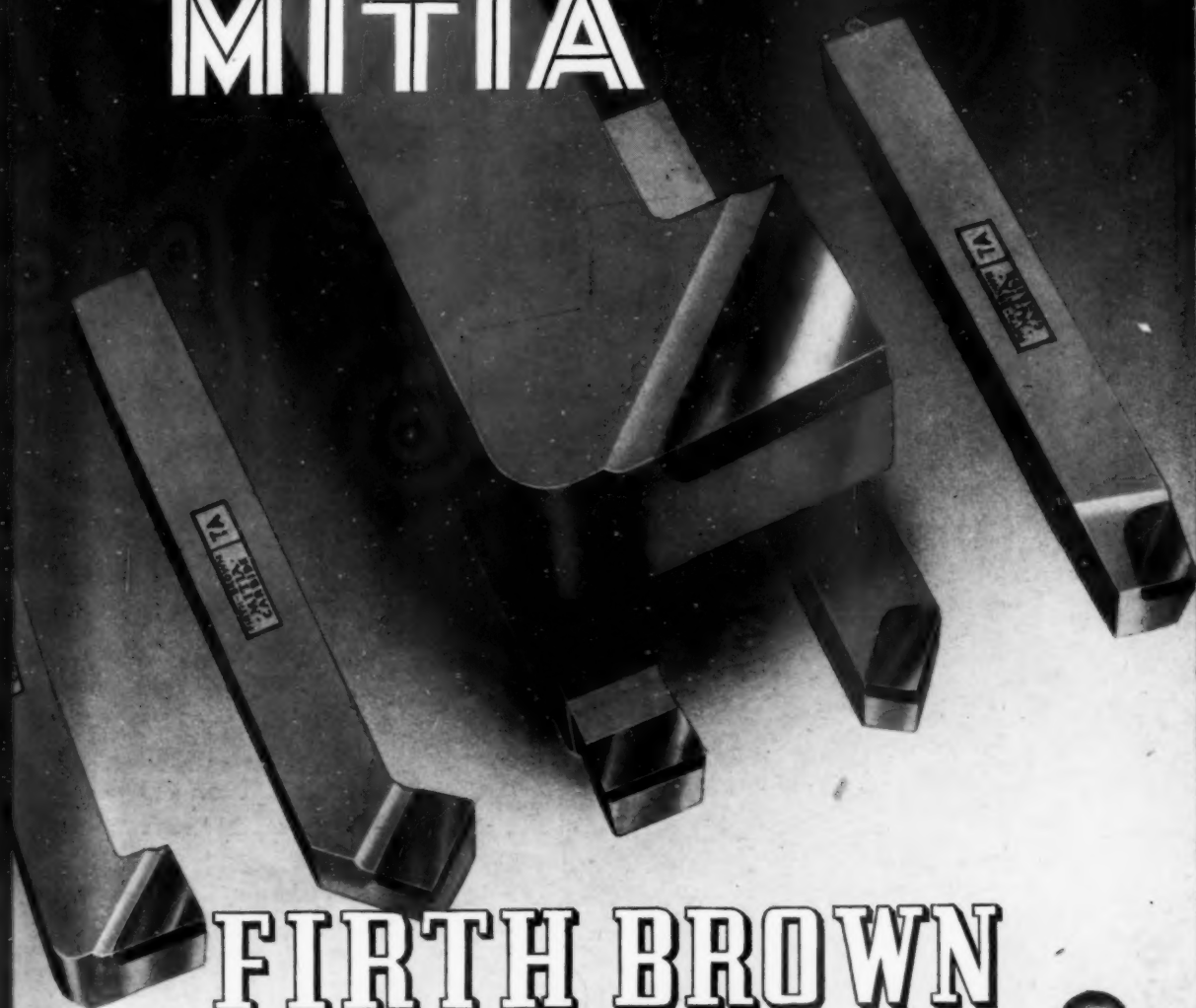


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Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 31, King Street West, Manchester, 3.
Telephone: BLA 2084. Telegrams: "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C. 2.
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A National Figure

EROS—designed by Sir Alfred Gilbert in 1886—unveiled by the Duke of Westminster in 1893—returns to Piccadilly after an absence of $7\frac{1}{2}$ years. He will see many changes, some which will please him and some which may not. He will undoubtedly be pleased to see the increasing use that is being made of aluminium alloys in our daily lives. This however will not surprise him for he has for 60 years focussed attention on aluminium—the metal used in his own construction.



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METALLURGIA

THE BRITISH JOURNAL OF METALS.

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JULY 1947

Vol. XXXVI No. 213

New Metals for Old

EARLY man probably became aware of the useful properties of metals through the accidental discoveries of gold, copper and meteoric iron, which are occasionally found in a practically pure condition. We know that gold and silver were used for the adornment of the human person, but there is no doubt that the feature of metals which would specially interest our ancestors would be the fact that metals could be hammered into useful shapes to form sharp-edged tools, which would be useful in war and peace. Eventually the use of metals extended, through the bronze and iron ages, to the steel age, which we may consider to be represented by the last two hundred years. The last hundred years has seen the rise of the steel industry, and at the same time the development of the science of metallurgy as distinct from the traditional arts of fabricating metals.

Looking back to see the path of developments which lie behind us is not only interesting but is often stimulating, and is the reason for Sir Edward Appleton, G.B.E., K.C.B., F.R.S., Secretary of the Department of Scientific and Industrial Research, choosing the above subject for the Edward William's Lecture, which he delivered before the recent annual general meeting of the Institute of British Foundrymen. In showing how new metals and new combinations of metals have taken the place of others, he directed particular attention to corrosion and protection of metals—deformation of metals, creep of metals, special materials for special purposes, electrical materials, magnetic materials, and a great discovery in cast iron, and some of the main points in his lecture are of more than ordinary interest and are given in the following notes.

In the last fifty years many metals and, particularly, combinations of metals have taken the place of others in the manufacture of things that people require and use. Progress in this respect has followed largely as the result of scientific developments, though, in this subject of metallurgy, it is not unpleasant to have to admit that empiricism has, occasionally, scored enormous successes, and there are still opportunities for "lucky dips"; but scientific research is a comparatively new form of human activity, while the extraction and fabrication of metals have been practised for thousands of years.

To-day, there are found in nature 92 elements, 68 of which may be classed as metals; and it is interesting that many of these metals, which not so long ago were merely chemical curiosities, have now found a place in science and industry. Of these, aluminium and magnesium are the most noteworthy. The physicist has recently shown how the transmutation of one known element into another can be brought about using atomic projectiles which penetrate to the heart of the atom and alter the structure of the nucleus; but the quantities involved are so small that these transmutations are

not of practical consequence at present. He has succeeded in producing two entirely new metals, neptunium and plutonium, the latter of which constitutes the fissile material in one of the bombs dropped on Japan. These two metals are produced in uranium rods which formed part of an atomic pile.

Although there are 92 elements in the earth's crust, the elements oxygen, silicon, aluminium, iron and calcium form over 90% and, with the elements potassium, magnesium, titanium, hydrogen, phosphorus, carbon and manganese, the total is raised to 96%. The two metals of aluminium and magnesium, which are likely to play an increasingly important part in the engineering of the future, contribute as much as 10% by weight to the earth's crust. Thus, 80 elements do not contribute more than 4% by weight, but more than half of these 80 elements are metals which are useful to our present civilisation.

In developing new metals for old, it should be noted that science has provided the metallurgist with methods of accurate measurement by which metals and alloys may be tested; thus, knowing the type of qualities wanted in a metal, it is possible, by measurements on specimens, to say how far any particular metal fulfils these requirements. The properties in question may be strength, hardness, durability, machinability, resistance to corrosion, thermal conductivity, thermal capacity and expansion, magnetic permeability or retentivity, and so on. About a hundred years ago our use of metals was limited—apart from the precious metals gold, silver and platinum—to wrought and cast iron, steel, copper, lead, tin, zinc, antimony and bismuth; and such alloys as bronze, brass and solders. To-day we live in the age of alloys, of which there are several thousand in everyday industrial use.

Many of the properties of alloys are not wholly determined by chemical composition, but by the fine details of their interior structure invisible to the unaided eye. And in the investigation of that structure the metallurgist uses many tools such as the optical microscope, the X-ray diffraction apparatus and the electron microscope. Under the most favourable conditions of shape and size, objects of the order of one hundred millionth of an inch in size should be capable of being observed. This size is comparable with the dimensions of molecules of somewhat complex inorganic compounds.

Metals tend to revert to their most stable form if nothing is done to prevent it. As a rule, the most stable states are the ores and what we call corrosion is largely the attempt of the metal to get back to this state. Generally, it is the action of oxygen which is the cause of corrosion, and one of the major problems is to prevent corrosion. It is estimated that the annual cost of treatment of the British output of iron and steel, used for constructional purposes, for protection against the atmosphere, is not less than £40 million.

An important victory in the war against corrosion

was the introduction by Brearley, in 1908, of chromium stainless steel, which originally contained 13% chromium. Later, the 18% chromium 8% nickel type and other austenitic high-chromium steels were produced. The latter were destined also to form the basis of many heat-resisting steels which have been developed in recent years. The effectiveness of the chromium in these steels is due to the fact that chromium oxidises very rapidly. A film of oxide is thus formed which is very tenacious and continuous; and it is this film which effectively stops further oxidation. Films of zinc, cadmium, lead and aluminium applied by very diverse methods are also used to reduce corrosion.

Particular attention was directed to the corrosion encountered in the condenser tubes of steam-driven ships, especially in battleships. In the first world war this was a source of great trouble. In more recent years, largely as a result of the researches of the British Non-Ferrous Metals Research Association, the condenser tube trouble almost disappeared despite the more arduous conditions which modern steam-raising practices impose. In between the wars, alloys had been developed consisting of either an addition of 1-1½% aluminium to the 70/30 brass or of a cupro-nickel alloy containing copper 70% to nickel 30% with the deliberate addition of 0.5% iron.

One of the most important problems facing the theoretical physicist is of explaining why metals break, or, in its converse form, why metals hold together. This problem has proved a most difficult one, and we have not yet got a theory of cohesion, the predictions of which agree with experience. Estimates of the strengths of single crystals of metals can be made by a number of theoretical methods, but the values obtained are always greatly in excess of those found in practice. According to calculation the maximum shear stress for a copper single crystal should be about 400 tons/sq. in., whereas the ordinary polycrystalline form of the metal has a yield strength of about 6 tons/sq. in. Recent developments of metallurgical science show that high-tensile strength is not readily attained in simple metallic states. It is obtained, in fact, in atomic arrangements which are markedly distorted. Such conditions are brought about by cold working, alloying, age hardening or quench-hardening.

Two national problems before us to-day are the efficient use of coal and the generation of electricity. These problems are limited in the efficient design of the steam-raising plant. The achievement of increased efficiency depends on the use of higher temperatures and higher pressures and this, in turn, demands new materials which can stand up to the new exacting requirements. New materials which the metallurgist has produced, have increased the efficiency of large electrical generators by more than 65% in the 15 years before the war, and progress is still being made.

One of the difficulties of using metals at high temperatures under prolonged stress is their liability to flow or creep and so change their dimensions. The subject has been of particular importance in connection with the development of gas turbines for aeroplane propulsion in which materials are subject to very great prolonged stress at very high temperatures. Under high temperatures and prolonged loading a piece of steel slowly stretches until it breaks. Creep is largely influenced by grain size. As the grain size diminishes the creep rate decreases to a minimum, beyond which, further decrease in grain size leads to increase in creep rate. Generally,

the phenomena accompanying creep are exceedingly complex, and the effect of grain size is sometimes obscured by other factors, such as the initial degree of cold work and the rate of cooling of the metal. Among the materials referred to, which have been developed for high-temperature service for gas turbines, were included, G. 18B, Rex 78, Rex 357, Nimonic 75 and 80.

Considerable attention was given to summarising developments of metals and alloys for the electrical and electronics industries, but it was appropriate that the concluding part should deal with cast iron, a material which has undergone remarkable improvements in recent years. Twenty-five years ago a cast iron with a tensile strength of 15-18 tons/sq. in. was considered exceptionally good. To-day, cast irons are commercially available with a tensile strength of 30 tons/sq. in. In addition, alloy cast irons have been produced to meet special requirements of industry, such as heat-, corrosion- and wear-resisting alloys.

The British Cast Iron Research Association has contributed to this progress by carrying out valuable fundamental research which has led to the development and to the production of new cast irons having very remarkable properties. From this kind of work have come the clues which have resulted in what has been described as the greatest metallurgical development in cast iron of the present century. Broadly this consists of taking a relatively high-carbon iron, which is easily melted, readily poured, and, without any special alloy additions, cast it so that it solidifies as a material having properties which rank it among the high-duty irons. This is done by treating the material so that on solidification the carbon is in the nodular instead of the flake form. This makes the metal similar in structure to malleable cast iron, but without its malleable properties. The exact nature of the process has not yet been disclosed, but it is rapidly nearing a commercial stage, certainly the results obtained suggest that the new material may lift cast iron on to altogether a new plane.

This descriptive method was used to illustrate the way in which scientific inquiry and experimental measurement, with now and again an empirical enterprise, have led to the discovery of better metals for practical use.

Physical science, as we know it to-day, grew originally out of the study of practical lore, and ever since it began to stand on its own feet as an independent theoretical interpretation and shorthand description of nature, it has often received fresh stimulus by coming back to practical problems. In the partnership of science and practice, the assistance rendered is by no means always in one direction. Science has grown out of practical knowledge, and it has nothing to gain, but much to lose, by neglecting to seek further inspiration and assistance from its origins.

The 11th International Congress of Pure and Applied Chemistry is being held in London, on July 17-24th inclusive, immediately following the Centenary celebrations of the Chemistry Society. Official delegates appointed to the Congress by the various countries number about 300 and include a delegation from Soviet Russia: individual members will bring the total attending the Congress to about 2,000. A very extensive programme has been arranged, and among the guests expected to speak at the gala dinner, to be held at the Dorchester Hotel, on July 24, is the Prime Minister, Mr. C. R. Attlee.

The Fatigue Strength of Some Tin-Antimony-Copper and other Tin-Base Alloys

By P. G. Forrester, M.Sc., A.I.M., L. T. Greenfield, M.Sc., A.I.M., and R. Duckett

Fatigue strength is one of the most important properties of white metals for bearings and some investigations are described on the fatigue properties of tin-antimony-copper and other tin-base alloys. The results show that the fatigue strengths of tin-antimony-copper alloys increase with increasing antimony and copper, but the effect of solid-solution antimony and eutectic copper is much greater than of either element in the form of massive compounds.

A NUMBER of different properties play a part in determining the relative value of an alloy as a bearing, but there can be little doubt that, so far as white metals are concerned, fatigue strength is one of the most important. Values for the fatigue strength at room temperature of a range of tin-antimony-copper alloys have been given by Macnaughtan,¹ and by Göler and Pfister.² So far as the authors are aware, however, no tests have been reported on these alloys at the normal service temperatures. The aim of the present investigation was to determine the fatigue strength at 100° C. of a range of alloys covering all the commercially-used tin-antimony-copper alloys, and thus to provide information concerning these alloys which would assist in the interpretation of laboratory bearing tests and service tests. The temperature of 100° C. was chosen as representing a reasonable average figure for the operating temperature of a bearing in service. An attempt has also been made to correlate fatigue strength with structure, and to assist in this correlation tests were made on a few other tin-base alloys possessing structures not obtainable in the tin-antimony-copper system.

Apparatus

All tests were carried out on rotating cantilever machines, similar to those described by Forrester and Chalmers,³ but with a modified loading mechanism. A diagram of the machines is shown in Fig. 1. The specimen, S, is gripped in a collet chuck, C, attached to the shaft of an induction motor. During test, the whole of the gauge length of the specimen is immersed in an oil bath, which is heated electrically by a heater, R, and controlled by a simple bi-metallic-strip type of thermostat. The motor may be swung back on the hinge, H, so lifting the collet away from the oil bath and simplifying the fixing of the specimen. The loading system consists of a ball-race, B, fixed to the free end of the specimen and attached by a universal joint to a rod, E. This rod is hooked onto a stout frame, F, which acts as a lever with its fulcrum at G. By applying a load, W, to the end of the frame a load is applied to the specimen. This load is equal to $(W \times l/a)$, where l is the perpendicular distance from the fulcrum to the line of action of the weight, and a is the distance from the fulcrum of the point of attachment of the rod, E, to the frame. The weight of the frame itself is counteracted by a balancing arm, J.

When the specimen breaks, the fall of the weight,

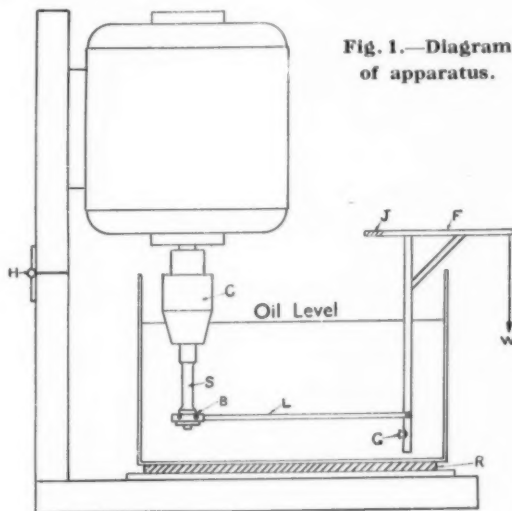


Fig. 1.—Diagram of apparatus.

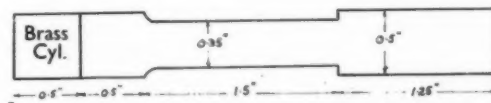


Fig. 2. Form of fatigue test specimen.

W, operates a switch which stops the motor and also an electric clock arranged in parallel with it, thus indicating the duration of the test.

Four of these machines were used in the investigation, two operating at 1,425 r.p.m. and two at 2,850 r.p.m. Tests on several different alloys indicated that difference in speed over this range had no significant effect on the fatigue strength.

Experimental Procedure

Alloys were made up from Chempur tin (99.99% purity), and the addition elements used were also of high purity. Check analyses were made on a number of alloys and found to agree very closely with the nominal composition. In the course of this paper, alloys are referred to by the percentages of addition elements, remainder tin being understood, e.g., 7 Sb/3½ Cu.

In general, alloys were cast from a temperature of 50° C. above the liquidus into a ½-in. diameter cylindrical chill mould at 110–120° C. To assist in holding

¹ D. J. Macnaughtan, *J. Inst. Metals*, 1934, **55**, 33.

² S. von Göler and H. Pfister, *Metallwirtschaft*, 1936, **15**, 342 and 365.

³ P. G. Forrester and R. Chalmers, *Engineering*, 1945, **150**, 41.

specimens in the chuck they were bonded onto a short brass cylinder, which was tinned on one face, heated to 250°C. and dropped to the bottom of the mould immediately before casting. For the sake of uniformity all specimens were thus bonded to brass cylinders, although the harder alloys could, in fact, be held satisfactorily without this precaution. After casting the specimens were machined to the dimensions shown in Fig. 2.

The first test on each alloy was made at a fairly high stress, and tests were then made at successively lower stresses until at least one failure was obtained after about $20-30 \times 10^6$ reversals. At least five specimens of each alloy were tested, and in some cases considerably more tests were made. In most cases, the results agreed satisfactorily with the experimental law of Eden, Rose and Cunningham,⁴ i.e., when log stress was plotted against log number of reversals, the results fell approximately on a straight line. The slope of this line did not differ greatly over the range of alloys tested. An example of the log S/log N curves obtained is given in Fig. 3.

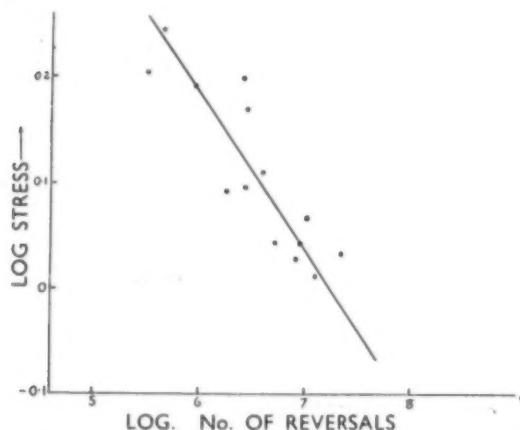


Fig. 3. Fatigue results for 7-3.5 antimony-copper alloy.

No evidence was found in any alloy of a significant departure from the exponential law at large values of N, i.e., there is no evidence of a true fatigue limit in these alloys. In this paper, fatigue strengths are quoted on a 10^7 cycles basis, the actual figure being obtained by noting the stress value at which the line cuts the ordinate corresponding to 10^7 cycles of stress.

I. Tin-Antimony-Copper Alloys

Compositions and Structures of Alloys Tested

A total of 34 alloys were tested, containing up to 7% of copper and up to 14% of antimony. Micro-sections of all the alloys were prepared, firstly as cast and secondly after fatigue testing: in the latter case, the specimen was cut from the gauge-length of a specimen which had fractured after at least 5×10^6 reversals of stress.

The structures of the as-cast specimens were in conformity with the phase-field diagram given by Pell-Walpole,⁵ and reproduced in Fig. 4. The following general observations were also made:—

(1) The matrix and compound grain-size of the

alloys cast under standard conditions was generally finer than that normally observed in commercial bearings.

(2) The antimony-containing alloys showed marked coring of the α -solid solution.

(3) With increase of copper content beyond 3.1%, the size of the SbSn cubes increased; this phenomenon has previously been observed by Ellis and Karelitz⁶ and by Nelson.⁷

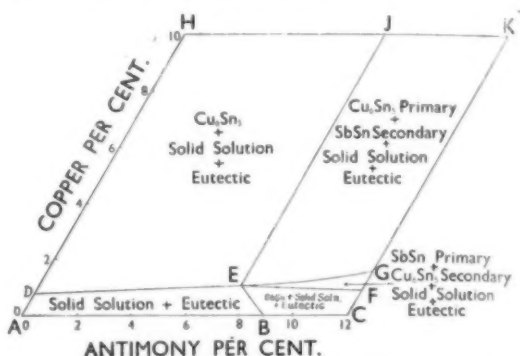
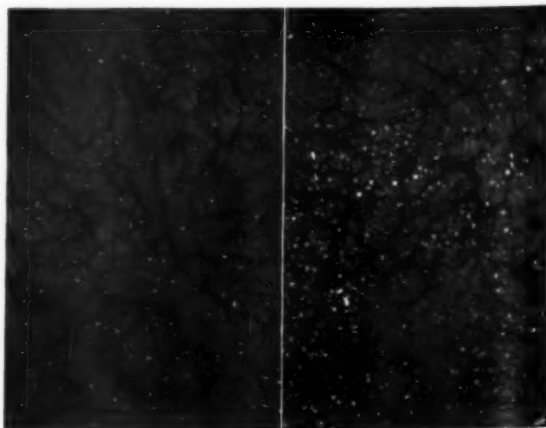


Fig. 4. Phase divisions of the tin corner of the tin-antimony-copper design.

The sole influence of fatigue testing on the micro-structure was to cause precipitation of fine particles of SbSn in alloys containing 7% or more of antimony. This is illustrated by Fig. 5 which shows micrographs of 7 Sb/0 Cu (a) as cast and (b) after testing. That such precipitation is liable to occur in such alloys is clear from the tin-antimony diagram of Hanson and Pell-Walpole,⁸ for the solid solubility of antimony in tin at equilibrium falls from about 10% at the solidus to about 3.1% at 100°C. Precipitation does not occur, however, in cast specimens annealed at 100°C. for 10-20 days. The stresses imposed in fatigue testing must, therefore, accelerate the attainment of equilibrium. It was observed that the alloys of higher copper content showed less tendency to precipitate SbSn.

6 O. W. Ellis and G. B. Karelitz, *Trans. A.S.M.E.*, 1928, **50**, 13.
7 G. A. Nelson, *Metals and Alloys*, 1932, **3**, 168.
8 D. Hanson and W. T. Pell-Walpole, *J. Inst. Metals*, 1936, **58**, 79.



(a) As cast $\times 150$. (b) After testing $\times 150$.
Fig. 5. Structure of 7 per cent. antimony alloy

4 E. M. Eden, W. N. Rose and F. L. Cunningham, *Proc. Inst. Mech. Eng.*, 1911, Oct., 839.
5 W. T. Pell-Walpole, *J. Inst. Metals*, 1942, **68**, 217.

It was also found in the course of the present investigation that very marked precipitation of SbSn occurs at room temperature in the worked surface layers of polished microsections. A number of polished specimens of various compositions were left for some months in a dessicator, then re-prepared by taking back to the last paper, followed by hand polishing. The structure of all the antimony-containing alloys was found to have changed completely, a very considerable amount of SbSn having been precipitated. Fig. 6 shows the structure of a polished and aged specimen of 7 Sb/0 Cu; the extent of precipitation is much greater than in the fatigue specimen (Fig. 5b). Some degree of precipitation also occurs in 3 Sb/0 Cu, (Fig. 7), although, according to Hanson and Pell-Walpole's diagram, the solubility is greater than 3% at room temperature. It is clear, therefore, that either the solubility of antimony in tin falls more than has so far been thought, or that equilibrium conditions in the highly-worked surface of a microsection differ very considerably from those in unworked metal.

To remove entirely all traces of abnormal structure from polished and aged microsections it was necessary to remove the surface layers with a file. The effect of polishing must therefore have extended to a considerable depth.

Fatigue Results

The fatigue strengths of the tin-antimony-copper alloys are shown in Figs. 8 and 9. In Fig. 8, fatigue strength is plotted against copper content for different antimony contents, while in Fig. 9 it is plotted against antimony content for different copper contents.

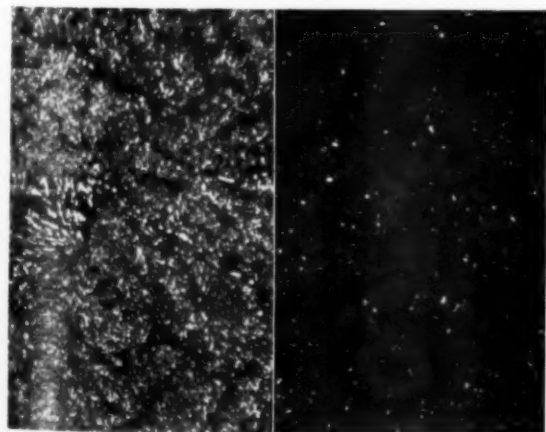


Fig. 6.

Fig. 7.

Fig. 6.—Structure of 7 per cent. antimony alloy, polished, aged and re-polished. $\times 150$. Fig. 7.—Structure of 3 per cent. antimony alloy, polished, aged and re-polished. $\times 150$.

For most of the alloys, the results obtained fell fairly closely on a straight line when plotted as $\log S : \log N$, and hence the fatigue strength on a 10^7 cycles basis could be estimated with fair accuracy. Statistical analysis of the results for three alloys indicated that the accuracy on a 95% probability basis is about ± 0.05 tons/sq. in. The alloys containing 7% of copper with 10, 12 and 14% of antimony, however, showed a much greater scatter of results. This is illustrated by Fig. 10 in which the results obtained for 14 Sb/7 Cu are plotted

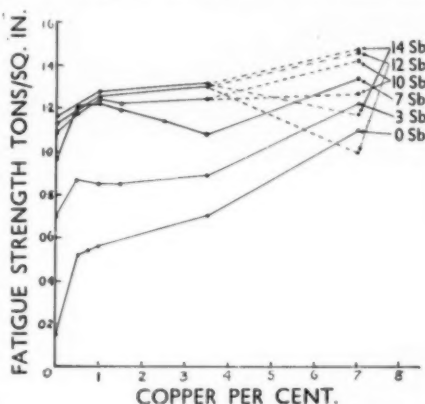


Fig. 8.—The influence of copper content on fatigue strength.

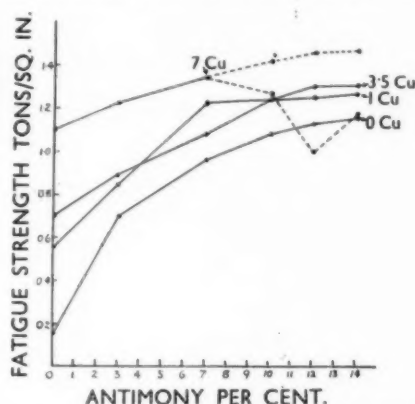


Fig. 9.—The influence of antimony content on fatigue strength.

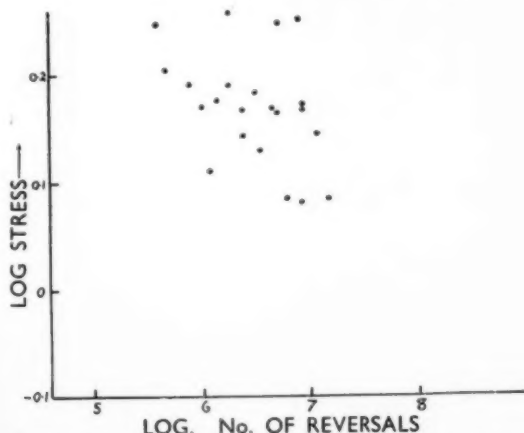


Fig. 10. Fatigue results for 14-7 antimony-copper alloy

individually. It will be seen that the results show a wide scatter, and all that can be deduced from them is an approximate range of fatigue strength. In Figs. 8 and 9, estimated maximum and minimum values for the fatigue strength of these 7% copper alloys are plotted, and the points obtained joined by dotted lines.

It has not so far been found possible to relate this scatter of fatigue results to any definite variable, such as structure or casting conditions. Further research is, however, being made into this problem.

Relationship between Fatigue Strength and Microstructure

In alloys of constant antimony content, addition of copper up to about 1% brings about a marked increase in fatigue strength. Copper up to about this percentage

exists in the form of fine particles of Cu_6Sn_5 , forming a eutectic with tin or a pseudo-eutectic with tin-antimony solid solution. Further increase in copper content results in the formation, under normal casting conditions, of relatively large needles of Cu_6Sn_5 , and these have a much less marked effect on the fatigue strength than the eutectic Cu_6Sn_5 . Increase of copper content from 1 to 3½% causes no significant increase in fatigue strength, except in antimony-free alloys, while in alloys containing 7% of antimony there is a significant reduction. Thus the 7% antimony curve shows a marked maximum at about 1% of copper, a fact which will be referred to again later. Increase of copper beyond 3½% increases the fatigue strength of alloys with 0, 3 and 7% of antimony, but, as noted earlier, with higher percentages of antimony results are erratic.

With increasing antimony content there is a continuous increase in fatigue strength (except with 7% of copper), but antimony in solid solution (up to 7% of antimony) has a greater effect than in the form of SbSn cubes. This is in agreement with the results of room temperature tests by Haigh (reported by Macnaughtan¹) and by Göler and Pfister.²

Influence of Casting Conditions

In addition to tests made on specimens cast under standard conditions, series of tests were made with 7 Sb/3½ Cu (a) with a higher casting temperature, and (b) with a higher mould temperature. Tests were also made with 10 Sb/0 Cu with a higher mould temperature. Increasing the casting temperature by 50° C. had little effect on the microstructure, but increase of mould temperature by 120° C. greatly increased the size of the compound particles. Fig. 11 shows the microstructure of 7 Sb/3½ Cu (a) cast under standard conditions, and (b) with a mould temperature of 230° C.

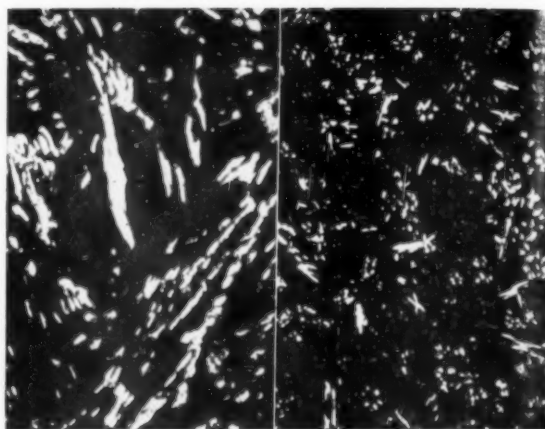
These variations in casting conditions had no significant effect on fatigue strength. The actual values are given in Table I:—

TABLE I.—EFFECT OF CASTING TEMPERATURE AND MOULD TEMPERATURE ON FATIGUE STRENGTH.

Alloy (Balance tin)	Casting temp., ° C.	Mould temp., ° C.	Fatigue Strength tons per sq. in.	Remarks
7% Sb + 3.5% Cu	355	120	1.08	Effect of Casting Temperature
7% Sb + 3.5% Cu	325	120	1.08	
7% Sb + 1% Cu	290	120	1.22	
7% Sb + 1% Cu	340	120	1.18	
7% Sb + 1% Cu	355	120	1.08	
7% Sb + 3.5% Cu	355	230	1.14	Effect of Mould Temperature
7% Sb + 1% Cu	290	120	1.22	
7% Sb + 1% Cu	290	230	1.23	
10% Sb	290	120	1.08	
10% Sb	290	230	1.17	

II. Alloys with Eutectic and Pseudo-Eutectic Structures

It has been noted that the relationship between fatigue strength and copper content for alloys containing 7% of antimony (Fig. 8) exhibits a marked maximum at about 1% of copper. This alloy, 7 Sb/1 Cu, corresponds approximately to a ternary peritectic complex and in the as-cast condition consists almost entirely of a solid solution with very small Cu_6Sn_5 particles. It was therefore considered desirable to investigate the fatigue properties of other tin alloys of similar structure, i.e., eutectics and pseudo-eutectics. The first three to



(a) Cast under standard conditions. $\times 150$. (b) Cast into mould at 230° C. $\times 150$.

Fig. 11. Structure of 7-3.5 antimony-copper alloy.

be examined were the eutectics of tin with lead, cadmium and zinc, respectively. The tin-zinc eutectic (containing 8% of zinc) gave a surprisingly high fatigue strength in view of its relatively low hardness (about 18 V.P.H.). Accordingly, tests were made with small additions of antimony to the 8% tin-zinc alloy. The tin-zinc-antimony system has been studied by Blondell and Laffitte,⁹ who showed that the relative proportions of tin and zinc in the eutectic are practically unchanged by the addition of small proportions of antimony. Up to ½% of antimony goes into solid solution; beyond this primary ZnSb forms.

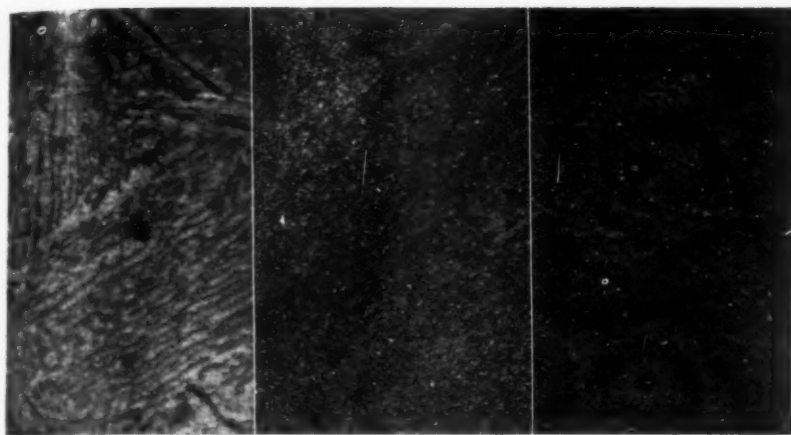
Other alloys included in this series were the ternary peritectic alloy of tin-antimony and silver, and the ternary eutectoid of tin, antimony and cadmium. These alloys were prepared and tested under the same conditions as were used for the tin-antimony-copper alloys. The results are given in Table II:—

TABLE II.—FATIGUE STRENGTHS OF EUTECTICS AND SIMILAR STRUCTURES.

Alloy (Balance Tin)	Structure	Fatigue Strength
55% lead	Eutectic	0.74
55% cadmium	Eutectic	1.08
8% zinc	Eutectic	1.18
8% zinc + ½% antimony	Ternary peritectic complex	1.25
8% zinc + 1% antimony	Ternary peritectic complex ZnSb	1.18
8% zinc + 3% antimony	Ternary peritectic complex ZnSb	1.14
7% antimony, 1% copper	Ternary peritectic	1.22
7% antimony, 3½% silver	Ternary peritectic	1.23
1% antimony, 5.5% cadmium	Ternary eutectoid	1.22

Two points of interest arise from these results. First, all the eutectic-like alloys, with the exception of tin-lead have an observed fatigue strength in the range 1.08–1.25 tons/sq. in. Since the accuracy of determination is about ± 0.05 tons/sq. in., the differences observed between these alloys are only just significant. Secondly, the addition of antimony beyond ½%, resulting in the formation of primary ZnSb , does not increase the fatigue strength; in fact there is some evidence of a reduction. This is analogous to the effect of increasing the copper content beyond 1% in the tin-antimony-copper alloys. In both cases, the maximum effect of the alloying element is obtained when just sufficient is

⁹ R. Blondell and P. Laffitte, *Compt. rend.*, 1935, **200**, 1472.



(a) 8 per cent. zinc. $\times 500$. (b) 8 per cent. zinc with 1 per cent. bismuth. $\times 500$. (c) 8 per cent. zinc with 0.1 per cent. tellurium. $\times 500$.

Fig. 12.—Structures of 8 per cent. zinc alloy showing effect of additions of bismuth and of tellurium.

added to form the ternary peritectic complex. Further additions, while increasing the hardness of the alloy tend to reduce its fatigue strength.

III. The Effect of Bismuth and Tellurium on Fatigue Strength

Suggestions have been made that small additions of bismuth or tellurium increase the fatigue strength of Babbitt alloys.

The effects (a) of 1% bismuth and (b) of 0.1% tellurium were investigated for three specific alloys, 7 Sb/3½ Cu, 7 Sb/1 Cu, and 8 Zn. The results are shown in Table III, from which it will be seen that both bismuth and tellurium have a significant effect on the fatigue strength of 7 Sb/3½ Cu and on 8 Zn. They have no significant effect on the microstructure of the tin-antimony-copper alloys, but both additions exert a very marked refining effect on the eutectic tin-zinc. This is illustrated by Fig. 12, showing (a) the normal structure of 8 Zn, (b) its structure with 1% of bismuth, and (c) with 0.1% of tellurium.

TABLE III.—THE EFFECT OF BISMUTH AND TELLURIUM ON FATIGUE STRENGTH

Basic Alloy (Bal. tin)	Addition	Fatigue Strength (t.s.i.)
7% Sb - 3.5% Cu	—	1.08
7% Sb - 3.5% Cu	1% Bi	1.22
7% Sb - 1% Cu	—	1.22
7% Sb - 1% Cu	1% Bi	1.24
8% Zn	—	1.18
8% Zn	1% Bi	1.30
7% Sb - 3.5% Cu	—	1.08
7% Sb - 3.5% Cu	0.1% Te	1.26
7% Sb - 1% Cu	—	1.22
7% Sb - 1% Cu	0.1% Te	1.28
8% Zn	—	1.18
8% Zn	0.1% Te	1.28

It is interesting to note that the addition of bismuth or tellurium brings the fatigue strength of 7 Sb/3½ Cu up to that of 7 Sb/1 Cu. The 7 Sb/3½ Cu alloy is of considerable commercial importance, and it is rather disconcerting that it should occupy a minimum point on the fatigue strength curve for 7% of antimony. The addition of 0.1% of tellurium avoids the occurrence of this minimum and may be worth considering as a practical measure.

Summary of Conclusions

(1) The fatigue strengths of tin-antimony-copper alloys at 100° C. increase, in general, with increasing antimony and copper contents, but the effect of solid-solution antimony and eutectic copper is much greater than of either element in the form of massive compounds. Beyond a certain point, the addition of further compound phase has an erratic effect on fatigue strength.

(2) There is evidence of a fatigue strength maximum at about 7% antimony, 1% copper, corresponding approximately to a ternary peritectic complex. Other tin-base alloys having uniformly fine structures give relatively high values of fatigue strength.

(3) The continued stressing of tin-antimony alloys at 100° C. brings about precipitation of fine SbSn particles. Such precipitation occurs to a much greater extent in the worked surface of polished micro-sections kept at room temperature.

(4) So far as has been ascertained, changes in casting conditions within a reasonable range do not significantly affect the fatigue strength of tin-antimony-copper alloys.

(5) The addition of 1% of bismuth or 0.1% of tellurium increases the fatigue strength of certain tin-base alloys.

Mr. Freeman Horn Retires

MR. FREEMAN HORN, who is retiring after nearly 40 years' service with the British Aluminium Co., Ltd., was educated at the City of London School. After a year's course in mechanical engineering at Battersea Polytechnic he took the electrical engineering course at Finsbury College under the late Professor Silvanus P. Thompson. After graduating he went abroad, first to Bohemia and afterwards to Switzerland, where he became test engineer with Brown-Boveri & Co., Ltd. He joined the British Aluminium Co., Ltd. in the early part of 1908 as their first development engineer, and was responsible under the late Mr. Arthur Jacob for the early development of uses of aluminium, particularly in the electrical industry. In 1910 and subsequent years he was the Company's technical representative in Central Europe and travelled widely for them before and after the 1914-1918 war. In later years his technical knowledge and considerable linguistic ability have found outlet in his task as Intelligence Officer, his Department forming a clearing house for all information relating to light metals and publishing the Company's well-known abstract journals, "Light Metals Research" and "Light Metals Review." Simultaneously, he has managed the Company's Special Products Department, formed to handle the Company's products other than metal. He has also for many years represented the Company on various associations and technical committees, at home and abroad.

Staff Changes and Appointments

Mr. E. H. LEVER (chairman), Sir CHARLES BRUCE-GARDNER, Bt. (deputy-chairman), Mr. W. F. CARTWRIGHT, CAPTAIN H. LEIGHTON-DAVIES, Mr. S. E. GRAEFF, Mr. R. A. HACKING, Mr. T. O. LEWIS, Mr. E. C. LYSAGHT, Mr. E. J. PODE and Mr. C. R. WHEELER have been appointed directors of the Steel Company of Wales.

Sir WILLIAM LARKE, K.B., has succeeded Sir Francis Joseph as President of the Society of British Gas Industries.

Mr. J. BATEMAN has taken up an appointment with Hard Metal Tools, Ltd., Coventry.

Mr. S. ROBSON has been appointed to serve on the Advisory Council on Scientific Research and Technical Development.

Mr. D. L. LESLIE DORAN, B.Sc., A.M.I.Mech.E., has been appointed technical officer of the Engineering Centre and is already working upon the organisation of the Advisory Service which is to be a particular feature of the Centre when it opens in Sauchiehall Street, Glasgow, at the end of September.

Mr. Doran has an extensive knowledge of general and experimental engineering and was recently in charge of engine development with Rolls Royce, Ltd. He will have the task of answering inquiries on technical subjects, meeting foreign buyers and putting firms in touch with one another.

Mr. JOHN ANDERSON, managing director of James Templeton & Co., Ltd., Mr. A. LEIGH ASHTON, F.S.A., director and secretary of Victoria and Albert Museum, Mr. G. W. LACEY, C.B.E., B.Sc., A.R.I.C., director and sales manager of British Aluminium Co., Ltd., Major F. L. STRATTON, managing director of Upsons, Ltd. and Dr. W. J. WARBOYS, chairman of the board of Plastics Division, Imperial Chemical Industries, Ltd., have been appointed additional members of the Council of Industrial Design.

THE ALUMINIUM DEVELOPMENT ASSOCIATION announce the following staff changes: Mr. W. J. McLAUGHLIN, C.A., has been appointed secretary of the Association in place of Mr. Davies who has resigned. Mr. J. D. BEDDOWS, B.Sc., who has been employed as chief metallurgist since June, 1944, has resigned to take up an important industrial position in the Midlands. Mr. J. C. BAILEY has been appointed technical officer to take over most of the duties previously carried out by Mr. Beddows. Mr. P. G. STUDHOLME, B.A., has been appointed to the editorial department of the Association.

Mr. L. V. CHILTON, M.A., has been appointed manager of the Intelligence Department of British Aluminium Co., Ltd., on the retirement of Mr. Freeman Horn, and Miss W. Lewis, B.Sc., information officer. Responsibility for the sale of special products is being transferred to the Sales Division under Mr. R. M. Warrington, who has recently given up his position as assistant development manager to become an assistant sales manager in Sales Division and to look after unwrought and special products. Mr. S. F. Derbyshire, manager of the alumina department of Production Division, will be responsible for technical matters affecting special products.

Mr. J. L. ADAM, C.B.E., M.I.N.A., chief surveyor to the British Corporation of Shipping and Aircraft has been elected President of the Institute of Welding and Dr. J. H. Paterson, F.R.I.C., Vice-President for 1947-48.

The Hon. C. M. McLAREN (chairman) and Mr. A. H. JARRARD, Mr. G. C. TROWBRIDGE and Mr. E. A. HYDE constitute the new board of directors of Diaplastics, Ltd., the Radio Heating Equipment company recently acquired by A. C. Wickman, Ltd.

A typographical error occurred in the qualifications of Mr. J. Rock Cooper, referred to in our last issue as having taken over active control of L. Oertling, Ltd., on the retirement of Mr. Malcolm Dunbar; these should have been Mr. J. Rock Cooper, B.Com., F.R.S.S., M.R.I., A.M.I.I.A.

Mr. G. C. TROWBRIDGE has been appointed managing director of Messrs. A. C. Wickman, Ltd., in succession to Mr. A. C. Wickman, who has resigned that position but remains chairman of the Company. Prior to his new appointment, Mr. Trowbridge was deputy to Mr. Wickman.

Mr. F. A. FOX, M.Sc., has recently received the degree of D.Sc. from the University of Birmingham. Dr. Fox is Assistant Director of the British Welding Research Association.

H. ROXBEE COX, Ph.D., D.I.C., B.Sc., F.R.Ae.S., F.I.Ae.S., has been elected President of the Royal Aeronautical Society for 1947/48. He takes office on October 1st, 1947.

Born in 1902 Dr. Roxbee Cox is the first of his generation to reach such a high office. Following the obtaining of first-class honours in Engineering the President-elect took an advanced course in aeronautics at the Imperial College of Science and Technology, and in 1924 joined the Royal Airship Works. In 1928 he was awarded the R.38 Memorial Prize of the Society for his paper on The External Loads on an Airship Structure.

Following the Government decision to discontinue airship work, Dr. Cox returned to the Royal Aircraft Establishment renewing his work on wing flutter, aircraft structures and aerodynamics, and in 1936 became head of the Air Defence Department at the Establishment.

In 1938 he was appointed Chief Technical Officer to the Air Registration Board, and on the outbreak of war seconded as Superintendent of Scientific Research at the Royal Aircraft Establishment. In 1940 Roxbee Cox became Deputy Director of Scientific Research in the Air Ministry, paying special attention to jet-propulsion gas turbines. At the Ministry of Aircraft Production as Director of Special Projects he became closely associated with all British gas turbine work.

In 1944 Dr. Roxbee Cox became Chairman and Managing Director of Power Jets (Research and Development), Ltd. On becoming a Government Establishment under the title of the National Gas Turbine Establishment he became its Director.

Dr. Cox is a Vice-President and Fellow of the Royal Aeronautical Society, a Fellow of the Institute of the Aeronautical Sciences, a member of the Aeronautical Research Council, of the Board of Governors of the College of Aeronautics, and of the London Mathematical Society, and Consultant to the Air Registration Board.

The Fulmer Research Institute

A Research Centre to Undertake Sponsored Research on a Wide Scale.

A bold venture has been successfully launched by the official opening of a research centre having adequate staff and equipment facilities to carry out metallurgical research on behalf of any firm. The idea of sponsored research is not new, but the principle has not previously been applied in this country. The object is to provide facilities for research and development for small and medium-sized firms, unable economically to equip and maintain their own research laboratories, who are anxious to keep abreast of larger and more established competitors at home and abroad. The opening ceremony is briefly described and reference made to the facilities available at this new Institute.

RESEARCH is becoming increasingly recognised as the essential basis of industrial progress. In the last few decades the remarkable progress achieved is largely due to the application of science to industry. In a comparatively short time the control of processes has changed from almost pure art to scientifically founded technology, based partly on applied science and partly on accumulated experience and traditional art. Gradually production control laboratories have become a necessity with individual firms in order that successful processes may be maintained within a specified range to control the accuracy and quality of a particular product. Usually these control laboratories are in the charge of the works chemist, works metallurgist or production metallurgist, who is directly concerned with the work being done in the various, and as a rule, he is fully engaged on the production side.

When problems arise that concern the materials used, the process employed or individual operations, they are frequently of such a character that careful research is necessary to effect a solution. Large firms find it economical to maintain central laboratories in which research and development work is carried out, with the object of securing the rapid improvement of industrial processes and products, developing new ones, and of solving manufacturing problems. The small and medium-size firms are at a disadvantage in this respect, since the cost of maintaining a separate research laboratory would render it uneconomical. There are, of course, several co-operative research laboratories functioning very successfully in the metallurgical field, on the other hand, what may be regarded as a private research laboratory is now available, which functions on somewhat similar lines as the Battelle and Mellon Institutes of America.

This new research organisation, known as the Fulmer Research Institute, was officially opened on July 2nd, by Sir Stafford Cripps, President of the Board of Trade, who realises as much as anyone that the vitality and progress of British industry depends upon research and development. At the official ceremony, which was attended by a very representative gathering, Sir Stafford was introduced by Col. W. C. Devereux, Chairman of the Institute, who gave a brief account of the background leading to this new venture.

Background of the Venture

Col. Devereux has been associated with the light metal industry for many years; a comparatively new industry, which has depended, to an abnormal extent, upon research and development to bring it into line with older



Sir Stafford Cripps and Col. W. C. Devereux at the opening ceremony.

industries in a relatively short time. The problem of providing adequate facilities for research and development, therefore, was of great concern to him. Outstanding among the problems he encountered in a new and struggling industry was, how to find the means of setting up research laboratories in small and medium-sized works on a scale adequate to do really effective work, in order to keep abreast of established competitors at home and overseas. Very favourable circumstances enabled him to support research on such a scale that it did, in fact, foster the evolution of techniques at a surprisingly rapid pace. Such circumstances are not likely to occur again, and it seemed to him that if only the services of a fully established research team, complete with all its equipment, could be engaged to tackle a particular problem; as one engages a lawyer, an accountant, an architect, or other specialist, a great many more manufacturers would be able to afford the benefits of applied research and the general level of our industrial techniques would be improved and made more efficient.

The idea is not new, continued Col. Devereux, the principle has been in successful operation in the United States for many years at such institutes as Mellon and Battelle. When he had the opportunity of visiting the States, he made a particular study of the system of sponsored research in operation there, and found in it what seemed to be an important development which had passed by completely in this country. He resolved to make every effort to introduce it in this country as soon as the opportunity occurred.

This opportunity did arise two years ago when he was forming a new group of companies and the question of providing research facilities for them had to be considered. The normal thing would have been to establish laboratories in each of the component companies—as, indeed, has been done for routine investigation and routine control—with perhaps a central research laboratory just adequate to deal with general problems. However, the circumstances were also favourable to the fulfilment of his dream of an institute for undertaking sponsored research on a far wider scale.

A considerable capital outlay was necessary, however the research was to be done and, for relatively little extra, laboratories and equipment adequate for the wider scheme could be found. At the same time, during the difficult initial period in which the Institute would have to settle down and build up its reputation, the companies of the new group would be facing an abnormal number of problems and would, therefore, be in a position to sponsor sufficient research at the Institute to give it a good start. But a positive declaration has been made to those in charge of the work of this Institute that the group of companies with which he is associated will stand in the queue on an equal footing with others, in the order of which their research requirements are presented.

He emphasised his belief in the necessity for the rapid application of the latest scientific advances to our manufacturing techniques, as a means of keeping up with our competitors all over the world and expressed his conviction that sponsoring research in an independent research institute, staffed with the best men available, is the ideal way of securing that end.

In calling upon Sir Stafford to perform the opening ceremony, Col. Devereux mentioned that Sir Stafford had been interested in this scheme from the very beginning and had given every encouragement throughout its development. For this reason alone it was most appropriate that he should officiate at the ceremony. In addition, however, since this Institute is dedicated to the service of British Industry, through applied industrial research, it was fitting that the man who now

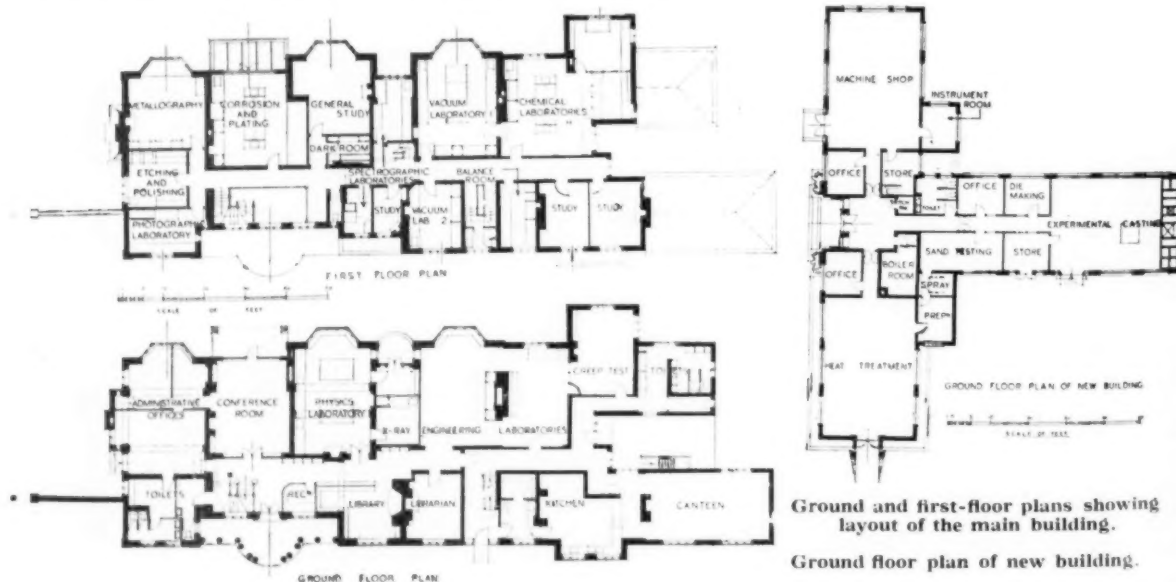
stands at the head of our industry and who numbers among his qualifications that of scientist, should give this project his blessing.

Speech by Sir Stafford Cripps

The idea of a common user Research Institute is a somewhat novel one in this country. Hitherto our research has been carried through in various ways starting with fundamental research in the Universities, the Department of Scientific and Industrial Research, and some governmental research institutions connected with particular activities such as the Royal Aeronautical Establishment at Farnborough. Then there have been the co-operative research organisations within particular industries assisted by grants from the D.S.I.R. which have dealt more with applied research, and finally, of course, the private research institutions of the great companies in which much most valuable work has been done, largely in applied research, though with some fundamental research as well. There are still a few consultants or private individuals who carry on research, but with the rising cost and complexity of research methods their number is now very few and is not likely to increase.

It is upon this basis of research that British industry depends for its vitality and progress. This is the true dynamic of our industrial production which, but for our research, would remain static and would die a slow and painful death.

You will observe from the short list that I have given of our methods of research that there are a number of gaps, the principal of which is in the range of the smaller but enterprising firm which cannot of itself afford to set up a Research Department proportionate to its vigour and enterprise. Even if such a firm can afford—as often is the case—to carry out some research it cannot afford to carry out all the research that it would like. Where then is it to go? It cannot go to a rival or competitor, its work is not suitable for a University as it is largely applied research, and so there is a gap and a most unfortunate gap. And what does that entail?



Ground and first-floor plans showing layout of the main building.

Ground floor plan of new building.

It means that the application of new principles and discoveries to production processes is delayed often for years and decades. The benefits of research do not, therefore, get through to industrial production in time to make them of real competitive value in the markets of the world. From the point of view of our export trade—and we are all now export-minded—that is most unfortunate. This Fulmer Research Institute is particularly designed to fill up a part of the gap. Indeed, it is the prototype of the kind of research organisations which might largely fill the gap altogether.

There are certain essential principles in a research institute which is to perform this general function for industry, all of which have, I believe, been enshrined in the plan of the Fulmer Institute. First, of course, it must be absolutely first rate in its staff and equipment, for its value to industry depends upon the quality of its services. It is because firms cannot individually afford first-class research staff and specialised equipment that they want to find a place where these facilities are available at a reasonable cost. But unless the facilities are absolutely first class they are of no value. Second, the results of research sponsored by an individual firm must be retained by that firm whether in the form of know how or patents. Otherwise the firms would largely lose the benefit of their expenditure. For the same reason parallel work for two different sponsors will not be engaged in without the consent of the earlier sponsor. This protection of the enterprise of an individual firm is essential in the existing circumstances as is secrecy and confidence wherever it is demanded. I hope that one day we shall emerge into a state of affairs where the scientific results of all research can be freely made available for the benefit of all, whatever its origin—but we haven't got there yet.

Third, the Institute should not be profit-making for the atmosphere of research and profit-making do not mix well together. What would be regarded as extravagance and waste in production is often absolutely necessary as an accompaniment of research. Though research should be carried out with reasonable economy and without the elaborate luxury of equipment that some people consider necessary, it must be allowed ample time and a wide range of experimental failure. It is the experiments which fail that are often as revealing as those which succeed.

Now all these three principles have been adopted in the setting up of this Research Institution. Another convenient arrangement that has been made is for members of the staff of the sponsor firm to come and work in the Institute at the research so as to be in a position to translate its results easily back to the factory.

In the first instance, the Institute will, I understand, concentrate upon metallurgical research—itself a wide enough field—though other departments of research will be taken up as the work develops. This is a wise decision, I feel, since it is far better to start with com-



Outside-view of the main building.

plete and first-class facilities for this one section of research rather than try to spread the facilities so widely over so many branches that they become too attenuated to be wholly effective.

There is one other aspect of the Institute I should like to mention. It will economise in scientific effort. To-day we are woefully short of first-class research staff. We haven't nearly enough to do all the jobs we should be doing. This Institute will enable the facilities to be available for a great number of firms which if they tried to provide them themselves individually would need a vastly greater staff—and that staff doesn't exist in this country to-day.

I hope, therefore, the Fulmer Research Institute will meet with every success and will by its success and growth justify and reward its founders. I hope, too, it may be the forerunner of other institutes on similar lines.

We, in the Government are doing our utmost to encourage the setting up of research institutions in particular industries. Under the new Industrial Development and Organisation Act it will be one of the functions of the Development Councils to be set up to encourage joint research organisations. But these alone, as I have pointed out, do not cover the whole ground. There will still be the gap even when they have been set up for many more industries than have them to-day. It is for that reason that the Government welcome so heartily this initiative.

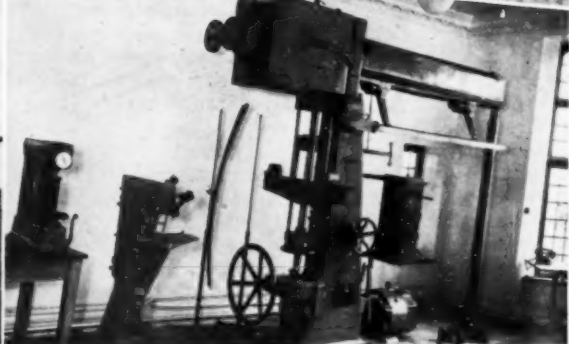
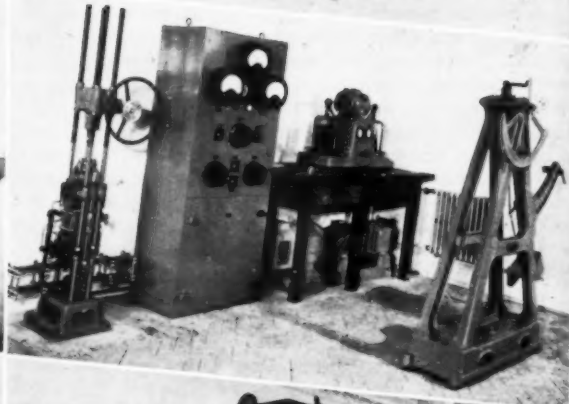
Response on Behalf of Directors and Staff

Speaking on behalf of the Directors and staff of the Institute, Mr. E. A. G. Liddiard, M.A., F.I.M., Director of Research, acknowledged the honour done them by Sir Stafford in opening the Institute, but realised that the best way of showing appreciation would be to do their utmost to make this bold experiment in industrial research a success. The will to succeed is the first requisite in any enterprise, and he assured his audience that this will to succeed, which is inspired by the Chair-

man, Colonel Devereux, permeates the whole of the Institute's staff. Although difficulties have been experienced in gathering together a team to work in the Institute, owing to shortage of scientific man-power, and in finding accommodation for them, he expressed himself as satisfied that the staff are in some instances brilliant, and without exception, enthusiastic.

A big idea lies behind this Institute. Eventually it is hoped to provide a research establishment equipped and staffed so that most types of industrial research can be undertaken. At the moment, however, the idea is bigger than the Institute, and it has been decided to start with metallurgical research, but the staff comprises a large proportion of chemists, physicists and engineers, all of whom are needed to deal fully with metallurgical problems, but who also are capable of dealing with other problems when they arise.

The Institute is organised in such a way that the staff work as a team. There is no division of the staff into watertight departments and all the brains and facilities of the Institute can, if necessary, be utilised in dealing with each problem. This will not have any significant effect on keeping the results of researches confidential, and it is bound to lead to successful results more quickly. The problems that are now being tackled and which it is desired to tackle in the future have clearly defined objectives and when those objectives are reached they will have an effect on industrial practice in this country. More problems of this type are sought, particularly those involving physical metallurgy, metal purification and distillation, the application of thermodynamics to industrial metallurgy, corrosion, protection and finishing problems and the development of new casting processes and procedures.



Top to bottom (left).—Main chemical laboratory. Metallographic section. Spectrographic laboratory.

Top to bottom (right).—Part of machine shop. Fatigue and impact testing. Tensile and hardness testing.

Some of the laboratory sections showing part of the equipment.

When a problem is submitted a decision will first be made, in a preliminary way, whether the Institute is likely to be able to tackle it, and whether it is likely to cut across any existing research contract. It is not intended to carry out simultaneously, research on the same or closely similar project for more than one sponsor, unless the sponsors agree to share in the work. If the decision is that the work can be undertaken the prospective sponsor will be asked to pay a retaining fee to cover the cost of a preliminary survey to define the problem, find out exactly what is involved, what staff and equipment are likely to be needed, how long the work is likely to take and what it will cost. In this preliminary stage it may even be found that the problem can be answered on the basis of existing knowledge, but if this is not so, a programme and an estimate of the cost will be submitted to the sponsor.

Although it is hoped to attract the private firm the Institute is prepared to take on work for groups of firms or for a particular section of industry if, for any reason, such work can be done better at the Institute than in any existing research establishment and where it is desirable that the results of the work should remain under the control of the people who pay for it. This does not mean that none of the work will be published, but the decision on publication and the time and form of the publication lies with the sponsor and not with the Institute. The Institute will advise publication wherever practicable and particularly where the results of the work can be covered by patents which are the property of the sponsor, since publication is a spur to the efforts of the research worker and enhances the reputation of both the sponsor and the Institute.

In a few final words Mr. Liddiard referred to the attitude of the founders of the Institute. The Institute is established as a completely separate unit. The Directors of the company will, of course, guide the policy and finances of the Institute and they will not seek information on the details of the research work in progress, other than those that they directly sponsor, nor will they divulge or make use of any information they may acquire incidentally. Mr. Liddiard gave his personal assurance that all reasonable precautions will be taken to prevent the results of any work, carried out for private sponsors, being divulged without permission to any other party—even including my co-directors. At the same time the technical resources, both material and intellectual, of our associates will be freely available if needed.

The laboratories were then opened to inspection. Mr. Liddiard and his colleagues answered inquiries made to them individually.

General Description of the Laboratories

The main laboratories and the library and administrative offices are housed in a converted Edwardian country house, situated at Stoke Poges, Buckinghamshire, and about 20 miles from London. The workshops, casting and heat-treatment laboratories are situated in a new building close to the original house. The buildings stand in approximately 10½ acres of ground.

The total floor areas available in all the buildings is approximately 20,000 sq. ft., of which some 7,600 sq. ft. are available for experimental laboratories, 1,000 sq. ft. for the workshops, 2,300 sq. ft. for laboratory storage, 2,275 sq. ft. for studies, offices and conference room, and 525 sq. ft. for library, the remainder being taken up by

canteen, kitchen, lavatories, corridors, etc. The general layout of the buildings is indicated in the plans shown.

Apart from the library and administrative offices, the main building houses the laboratories comprising the metallographic and photographic section, which consists of three rooms: a corrosion and plating laboratory; spectrographic laboratories; vacuum laboratories; engineering and creep laboratories; chemical and physics laboratories. These are remarkably well equipped as will be seen from some of the illustrations.

In the new building is located the experimental casting laboratory which is equipped with a 20 KVA EFCo medium frequency (3,000 cycles) induction furnace, motor generator type, equipped for melting in special atmospheres or in vacuum; a 27KVA EFCo silit rod electric resistance furnace capable of melting 38 lb. of aluminium; a Morgan oil-fired furnace of 20 lb. capacity; and a tilting indirect arc furnace suitable for precision casting. A large electrically-heated and controlled core-drying oven, which can also be used for low-temperature heat-treatment, and a sand mill are also installed. In an adjacent room is a small pattern and die-making section and a sand-testing laboratory. Facilities are provided for producing the "lost wax" type moulds used in precision casting. Adjacent to the sand-testing laboratory is a booth in which paint, metal and other forms of spraying can be carried out.

The heat-treatment department is equipped with a Birlec forced air circulation furnace, primarily for heat-treatment of light alloys and suitable for temperatures below 700°C. and three other furnaces of varying size and shape for general heat-treatment. The machine shop is also housed in the new building and, as will be noted in the illustration, is well equipped.

Sponsored Research Service

This non-profit making organisation, operating on a system of sponsored research, offers a service to industry which is quite new in this country. To small and medium size works, such as those of which sections of British industry largely consist, the system offers the opportunity of carrying out really effective independent research using highly qualified scientists, and the most modern equipment, on a scale equal to that of the largest industrial laboratories. To the large business, industrial association, or Government department also the Institute offers its services, not to compete with existing research departments but, with their co-operation, to supplement existing facilities by tackling those problems whose demands in time, staff and experimental equipment, may be beyond their scope.

The Institute offers to the sponsor the opportunity of utilising the services of a complete research organisation already established as a going concern without incurring any obligation other than payment of the mutually agreed amount stated in the contract. Sponsors may, if they wish, send their own nominees to work in the Institute under the Industrial Research Fellowship system.

The Institute is open to consultation on everyday problems, but it is primarily a technological fact-finding organisation whose work consists mainly of laboratory and field investigations aimed at the evolution of new industrial processes and materials or the improvement of existing ones.

Engineering and Marine Exhibition

THE Engineering and Marine Exhibition which opens at Olympia, London, on August 28th to September 13th will present at least one interesting refutation of the carefully circulated story that British Industry—tied by crippling controls, shortages of raw materials, manpower and fuel—has neither the resilience nor the initiative to weather the international marketing storms. This year's Exhibition embraces the whole of the Main Hall and National Halls at Olympia, together with their galleries—an increase of over 45% on the 1937 Exhibition. All available space is taken: mostly by firms who have been regular supporters of this British Exhibition. Also represented are many newer industries whose advent is an index of the war-induced subdivision and specialisation in the trades ancillary to shipping and engineering.

The general arrangement of the Exhibition follows the long adopted practice of sectionalisation: but it will be seen that whilst all the old sections are larger than ever the newer sections are equally well supported to the limits of the space available.

In the Foundry Section—a feature started some years before the war—the contrast between the production methods of pre- and post-war eras will be demonstrated by the exhibits. The march of mechanisation, the wide increase in the use of electricity and compressed air—and the improvements in lifting and shifting equipment, will tell their own story. But attention will also be directed to the improved quality of the products of the foundry.

The Welding Section too, reflects the considerable advances which have been made in this most important sub-section of the engineering industry. Here, both the electrical engineer and the machine tool designer have made their presence felt, and their influence is written large upon the many up-to-date welding and cutting plants and their accessories which will be on show. Of considerable technical and popular interest will be demonstrations by divers of under-water metal-cutting by torch.

Amongst the new sections is that devoted to electricity—embracing the whole gamut of generation, transformation, distribution and utilisation of power in engineering, on shipboard and in signalling. At least two of the more popular feature demonstrations of the Exhibition are made possible by firms exhibiting in this section or using equipment sponsored by such exhibitors. The public will be able to watch the reported progress of ships at sea by means of shore-to-ship teleprinter service working on the stands of a world-famous underwriting organisation. Messages between visitors and their friends on the high seas may also be handled.

Another demonstration of interest, as much to the technician as to the less well-informed man in the street, will be the first public glimpse behind the screens of Radar in its modern applications. Upon the roof of Olympia will be a radar station fully equipped with the most modern devices to enable the onlooker to "see beyond the horizons" of the vast canopy of the Exhibition building.

Readers are advised to visit this Exhibition and learn for themselves that Britain's technical, engineering and commercial ability was never higher and, with increasing supplies of basic materials, can confidently face the future.

An Exhibition Building in Aluminium

It is noteworthy that the Ministry of Agriculture exhibition at the Royal Show recently held at Lincoln was housed in an aluminium alloy structure having a total length of 342 ft. Designed and constructed by Structural and Mechanical Development Engineers, Ltd., of Slough, Bucks., a subsidiary of Almin, Ltd., this structure is a development of a smaller building—approximately 75 ft. long—which is being used by the Ministry of Agriculture at agricultural shows throughout the country. Standard aluminium alloy sections 9 ft. long are used for these buildings, enabling the size to be varied at will.



Details of construction of the aluminium building at the Royal Show illustrating some of the girders and roof trusses.

Speed of erection on site was an essential consideration in the design, and the following erection figures will be of interest:—

The 75 ft. building was erected at Cambridge in one and a half working days. The building at the Royal Show was L-shaped, comprising one length of 198 ft. and the remaining part 144 ft. long: the former consisting of 22 standard 9 ft. sections, and the latter 16 standard sections. This building was erected in nine working days. In each case unskilled labour was employed. These buildings can be rapidly dismantled, transported and re-erected on another site.

Awards

Mr. T. MAKEMSON, M.B.E., has been presented with the E. J. Fox Gold Medal in recognition of his services to the foundry industry. He has been secretary of the Institute of British Foundrymen for 21 years.

Mr. REGINALD S. BROWN, chief metallurgist at Rylands Bros., Ltd., and a director of the Whitecross Co., Ltd., has been awarded the M.B.E. for scientific services to the Government departments during the recent war. Dr. A. B. EVEREST has been awarded the Oliver Stubbs Gold Medal by the Council of the Institute of British Foundrymen.

Sir CLIFFORD PATERSON has been awarded the 1946 James A. Ewing Medal by the Council of the Institution of Civil Engineers.

Mr. BASIL GRAY, B.A., has been awarded the British Foundry Medal for his paper, "The Production of Grand Slam Bomb Castings," presented to the 1946 Conference of the Institute of British Foundrymen.

Production of Magnesium Alloy Castings

Some Commercial Applications

By G. B. Partridge, A.I.M.

Production Metallurgist, Elektron Foundry, Birmingham Aluminium Castings (1903) Co., Ltd.

In this article, the final of a short series on the subject, the author discusses some factors influencing the use of magnesium alloy castings in general engineering. As an engineering material application is divided broadly into two classes, that for which its properties make it ideally suited, and a second class for which other materials are in general use because suitable magnesium alloys were not available when the original castings were designed. The question of cost is considered, and special attention directed to design characteristics. Several examples showing developments in the application of these alloys are illustrated.

TO many in the various commercial branches of the engineering industry the term magnesium alloy conjures up a vague notion of "a special sort of aluminium" which is ultra light yet expensive and does not find much application outside the aircraft industry. This is quite wrong, and it is proposed to examine these views whilst considering what has already been done and what can be achieved in the field of everyday or commercial industry.

Zirconium Alloys

Before proceeding with this treatment of the subject which concerns the well-established magnesium-aluminium type alloys already listed in a previous article¹ it is necessary to call attention to the newly developed zirconium containing alloys, which have been evolved after long and tireless effort by research workers at the laboratories of Magnesium Elektron, Ltd. The outstanding characteristics of these new alloys, apart from their extremely fine grain, are the increased 0.1% proof stress which is of the order of 9.5 tons/sq. in. and the enhanced resistance to corrosion, this latter comparing favourably with the magnesium-manganese alloy AM503. It must be mentioned that a comparatively high elongation accompanies this high-proof stress. Progress to date has been fully reported recently by Major Ball² and there is little doubt that these alloys represent the most outstanding advance made in ultra-light materials now made available to the engineer and designer. The aircraft industry with revolutionary

designs now taking shape, especially in regard to jet engines, will no doubt welcome the new strong zirconium alloys, and it may be expected that first applications will be made in this sphere.

A Relatively New Material

The first and most important consideration to bear in mind when referring to magnesium is that it is a comparatively new engineering material, and having got this fact firmly fixed it will be seen that its mode of application divides broadly into two main classes: (1) That class of specific applications where its properties make it the ideal material for the job, indeed in some instances the only material; and (2) where it replaces some existing part previously made in other material simply because magnesium alloy was not available when the original casting was designed. It may be, and actually is, often found to be, that the original has disproportionate weight to strength required of the part and the substitution of magnesium alloy results in many advantages not apparent at first glance. Although the commercial aircraft industry will continue to use increasing amounts of the material, considerations in this article will be limited exclusively to other engineering applications.

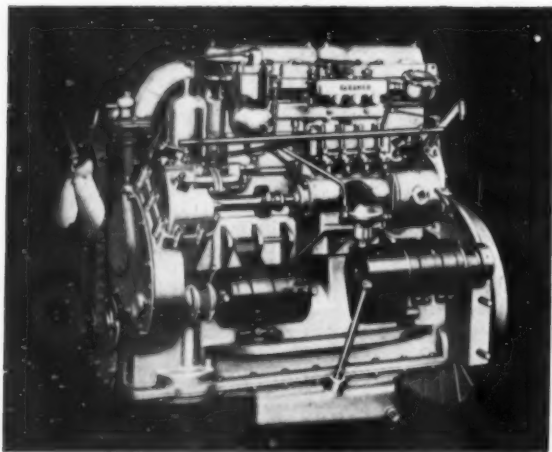
The Question of Cost

Is magnesium cost competitive? This is not usually regarded as a technical point and, providing that the material under discussion is only needed for war purposes, this is not surprising, as the best must be used whatever the cost. With peaceful applications, however, the position is

radically changed, and the cost of the product assumes a more important position from which few technical arguments, however sound, can dislodge it. Pride of place is usually given to this factor in making a choice when determining the suitability of a material; it must, therefore, be fully examined, since many engineers are still under the impression that castings made from magnesium alloys are unduly expensive.

The ingot material, supplied for commercial castings manufacture, bears no resemblance to its contemporary frequently marketed as "commercial aluminium"; it has a rigidly controlled specification with well-defined mechanical properties and is comparable in this respect with the better types of aluminium alloy. On a volume basis the price of magnesium alloy is about equal or less than present-day prices of many of the specified aluminium alloys and frequently possesses superior properties. Previous articles have demonstrated the intricacies of magnesium-castings manufacture and show that overhead costs are fairly high; but, with rising costs of aluminium of reliable specification, magnesium is becoming more competitive. The cost to the customer, however, is decided finally by: (a) Simplicity of design of the part; (b) perfection of pattern and moulding equipment, both of which decide the ultimate factor; (c) the speed of production; and it is worth while reiterating the importance of discussing a potential job with the foundry experts in the earliest possible stages. As a general rule, the more solidly built and compact a part is the cheaper it will be, for castings such as frames or other skimpy types which require a

¹ *Metallurgia*, November, 1946. Author.
² Outstanding properties of the magnesium/zirconium alloys. *Metallurgia*, January and February, 1947. Major C. P. J. Ball.



Courtesy of L. Gardner & Sons, Ltd.

Fig. 1a.—The Gardner 4LK high-speed oil engine

large moulding box, and therefore need a large amount of work to produce relatively little, will inevitably be more expensive. The term "simplicity" used above does not mean that only simple designs can be cast in magnesium but that unnecessary frills will increase the cost.

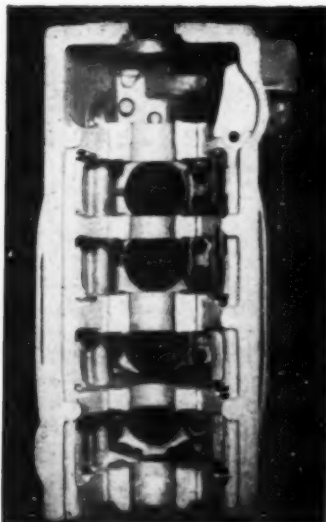
The beneficial weight factor of the magnesium makes its cost competitive with many aluminium applications, but with cast iron the position is more difficult, and it may be assumed that at present iron castings are usually cheaper *piece for piece*. To accept this fact, however, without further investigation would be sheer folly, as no account has been taken of two most important points: (a) manhandling and (b) machining. Potential users of magnesium castings are urged to visit magnesium foundries and obtain practical evidence of what it means to be able to lift and transport castings which, if in cast iron would need two or more men or a crane; the section on machining which follows later is self-explanatory and applies both to aluminium and cast iron. Full appreciation of the economics of magnesium castings can only be found by viewing the job in its entirety, taking into account the lower transport and handling charges, and the much reduced machining costs. In addition this weight saving has a permanent influence throughout the life of the casting. In his talk to the Detroit engineers last year³ the distinguished metallurgist, Dr. Hanawalt drew a cost comparison by asking his listeners to imagine that the positions of iron and steel and

³ The industrial significance of the basic characteristics of magnesium. J. D. Hanawalt. *Metal Progress*, March and April, 1946.

magnesium were reversed; had magnesium the benefit of 50 years of commercial development usage the fact of iron ever becoming cost competitive with magnesium would seem very doubtful. Under such a fancied argument the high-melting temperatures, refractory problems, high density, the rusting problem, etc., would contrast badly with the low-melting point, low weight magnesium.

Fundamental Characteristics and Design Principles

Density.—The ultra light weight of magnesium alloys is the basic fact around which all other technical data must revolve; and it is elementary to note that for a given weight magnesium will occupy a much larger volume than most other materials, which is a most important characteristic. On purely theoretical grounds, even taking this ultra light weight into account, it sometimes does not seem possible that magnesium can be used to replace a similar part made of high-strength cast iron, steel or aluminium, but stress calculations referring only to the strength/weight ratio are not the only criterion for a casting made in any material must have a definite minimum section to be made at all and must also possess sufficient bulk to resist buckling forces: in addition there is the necessity to include bosses and flanges, etc., whose size is controlled by the bolts and fitments used in general assembly and not by simple strength requirements. Castings in other metals which have



Courtesy of L. Gardner & Sons, Ltd.

Fig. 1b.—Elektron crankcase for the 4LK oil engine.



Courtesy of A.E.C., Ltd.

Fig. 1c.—Elektron sump for high-speed oil engine.

Castings by Birmingham Aluminium Castings (1903) Co. Ltd.

been made with enlarged sections by reason of the above will be considerably lightened when made in magnesium alloy. The maximum advantage that can be saved by the substitution of magnesium for other materials is when an increase in cross sectional dimension can be tolerated. Restriction imposed on this factor will result in inefficiency of design; for this and other reasons the practice of allowing a pattern, used for producing a part in aluminium or cast iron, to make a trial in magnesium, without design alteration, is to be discouraged. Such a casting may fail under unfair conditions imposed upon it and cause unjustified condemnation of magnesium castings generally.

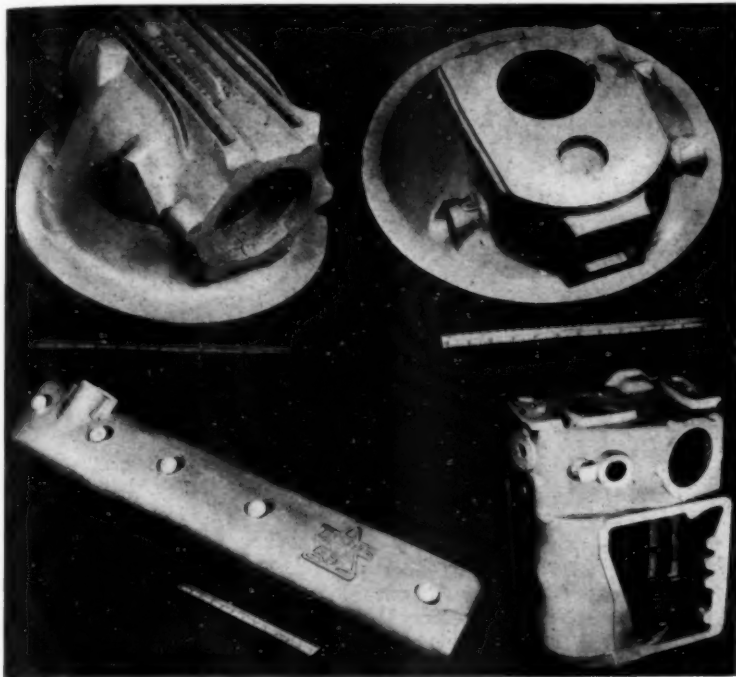
The heavy vehicle industry provides notable examples of the use of Elektron castings and a crankcase for the Gardner 4LK is shown in Fig. 1. Particular note should be taken of the sturdy lines of the crankcase, the robust bosses, pillars, excellent depth of section and adequate bearing areas, also illustrated is a typical heavy engine sump, these whilst not stressed castings provide perfect examples of reducing dead weight. Fig. 2 shows other types of castings used in this industry, the rear axle worm casing is subject to considerable stress and, owing to the overall heavy section in the original cast-iron design, makes a substantial contribution to weight saving. The other castings illustrated are typical of many thousands which continue to

Worm casing for a rear axle.

Courtesy of Kirkstall Forge, Ltd.

Clutch housing.

Courtesy of John I. Thornycroft & Co., Ltd.



Courtesy of A.E.C., Ltd.

Courtesy of A.E.C., Ltd.

Valve cover.

Gear box.

Fig. 2.—Examples of magnesium alloy castings used in heavy oil engine industry.

Castings by Sterling Metals, Ltd.

be successfully used in heavy vehicle transport, increasing the pay load of the vehicle.

It is pointed out in a very useful American publication⁴ that the strength or stiffness of a structural member increases with the second or third power of the thickness or depth of the section with such factors as bending or buckling stresses and that even small increases in cross section if judiciously placed, whilst not appreciably increasing the weight, will result in disproportionately great increases in strength and stiffness. A classical example of the way in which a heavy section can be redesigned for magnesium is shown in Fig. 3 taken from the

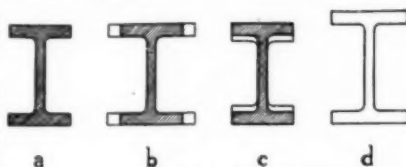


Fig. 3.—Methods of increasing sectional shape to use magnesium alloy. The most efficient change is from (a) (Steel) to (b) (magnesium alloy). After E. J. De Ridder. "Technology of Magnesium and its Alloys," by Beck.

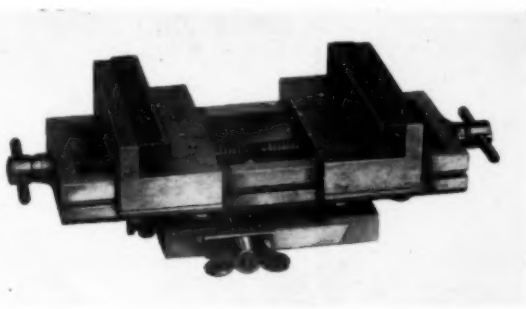


Fig. 4.—Elektron clamp for special type of machine shown above. Castings by Birmingham Aluminium Castings (1903) Co., Ltd.

work of E. J. De Ridder,⁵ and illustrates that volume increases in geometrical proportion result in maximum weight economy. Being able to use a greater bulk of magnesium by virtue of its light weight eradicates the problem of local buckling forces which may impose restriction on the use of other materials and the extra sturdiness which automatically follows from the use of a more sturdy component is very useful because it endows the part with extra ability to take punishment—i.e., accidental distortion or stresses which may be imposed, which cannot be calculated beforehand, are more likely to be successfully resisted. A most useful application of weight saving by the use of magnesium is in those cases where the article has to be made bulky in any material—i.e., space has to be filled apart from any considerations of severe stress. Finally it should be noted that the light weight of the magnesium component itself can materially reduce many stresses which may be encountered and one example of this is the case of reciprocating parts where the self-destructive action of the part increases in direct proportion to its own weight. Some ideas of the benefits which can accrue from light-weight parts are illustrated in Fig. 4 which shows a clamp used during the process of engine turning. This clamp which is attached to the machine (also shown) moves at high

⁵ Technology of magnesium and its alloys. (Beck). F. A. Hughes & Co., Ltd.



Courtesy of G. Hunt & Son,

⁴ Designing with magnesium. American Magnesium Corporation (1945)



Fig. 5.—Range of Elektron castings for cigarette-making machinery.

Castings by Birmingham Aluminium Castings (1903) Co., Ltd.

speed and is a reciprocating part; considerable inertia forces have continually to be overcome, and a magnesium alloy is claimed to be the ideal material for the purpose.

Modulus of Elasticity.—The important property E is 6.5×10^6 lb./sq. in. for magnesium alloys, and by direct comparison with other materials, is low, and has to be taken into account when components are being designed in this metal. It should be pointed out, however, that the compensating specific gravity allows for slightly increased volume which, if efficiently placed, will give equal, if not better stiffness than from the materials in more common use, and will allow for considerable saving in weight. It is, perhaps, hardly necessary to point out that where rigidity is concerned, slightly increased depth is the most efficient way of compensating for this difference in modulus.

Such designs accompanied by judicious increases of section thickness—as discussed above will eliminate the criticism that the low modulus is a danger, in fact, it should be emphasised that *weight for weight* magnesium members possess relative stiffness of over twice that of aluminium and nearly 19 times that of steel. Where volume is restricted resulting in inability to apply the necessary bulkiness the low modulus is a disadvantage and will rule out certain applications.

There are certain compensatory advantages which accompany a low modulus, one being the ease of a part

subject to elastic vibrations. In such cases, a specific strain or deflection will induce a lower stress within the magnesium than in a corresponding part made of other materials possessing a higher modulus. Another function of the low value of E is that noise is frequently reduced in a given assembly by the inclusion of some magnesium parts.

Illustrated in Fig. 5 are castings for cigarette-making machines. This application demonstrates the use of the material for rigid assemblies and gives an idea of the enormous potentialities of magnesium castings properly applied in this fashion. Textile machinery processing and packaging machinery for all trades, lathes and general engineering machinery of this type, especially if required to be portable, are but a few of the fields that magnesium castings can render more fertile. Apart from the advantages inherent in the machines themselves there is the question of the greatly reduced load on the floors upon which the machines are installed, this may mean the difference between a new building and an old one, or the introduction of several storey working where ground floor or heavy reinforced concrete was the only previous possibility.

Resilience.—As a consequence of their low modulus of elasticity the magnesium alloys possess relatively high resilience which is the capacity of a material to absorb shock in the elastic range. Perhaps one of the best known of magnesium applications is

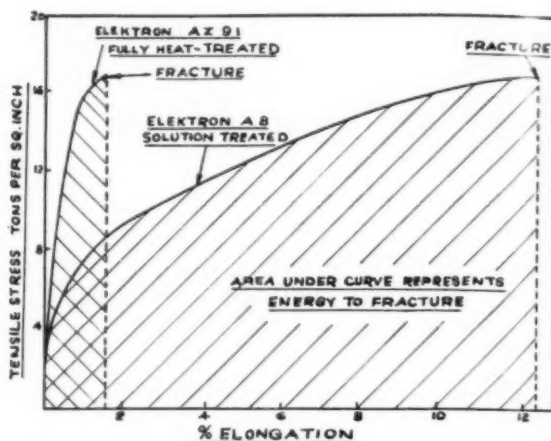


Fig. 6.—Comparison of energy absorbed in fracturing Elektron A8 and Elektron AZ91. After A. Fisher.

that of aircraft landing wheels which are regularly subjected to shock and impact forces; the alloy used for this application (Elektron A8 to D.T.D. 289A) has an elongation of about 12% and possesses considerable toughness (which enables a part if severely overstressed to deform plastically instead of breaking short). Fig. 6 gives an illustration of the energy absorptive capacity of this type of material which is of particular value in the case of aircraft wheels because the absorption of the shock and impact forces encountered in a forced landing may prevent large loss of life. On reference to tables it may be noticed that the impact values for the magnesium alloys are comparatively low and may lead to some scepticism of the material's



Courtesy of Castings, Ltd.

Fig. 7.—A typical Elektron Moulding box.

Casting by Birmingham Aluminium Castings (1903) Co., Ltd.

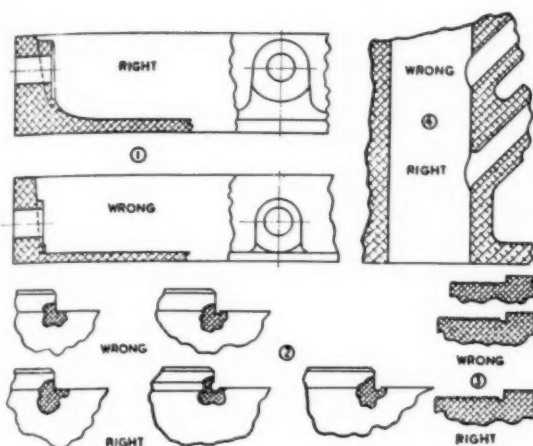


Fig. 8.—Some design and machining recommendations to reduce service failures: (1) A modification for spot facing; (2 and 4) ample fillets and radii reduce stress concentrations. From "Designing with Magnesium," American Magnesium Corporation.

capabilities, however, testing by this means does not take into consideration the effect of resilience and impact figures alone are very misleading. The question of energy absorption, elongation and other properties under conditions of specific strain are profitably discussed in an article by A. Fisher⁶ and refer particularly to the magnesium alloys.

⁶ The importance of ultimate extension as an engineering property of materials. A. Fisher, A.I.M. Metallurgy, June, 1946.

from building up to serious proportions, such a "safety valve" reduces stresses and increases fatigue strength. The importance of this property has only begun to take shape in recent years, and although its precise measurement is difficult more information will no doubt be available in the future.

Fatigue Strength.—Fatigue strength may be defined as that alternating stress which a casting or part of a casting can endure permanently and is of particular importance when considering engine parts. The magnesium alloys in general possess good resistance

An interesting application which has to withstand considerable abuse is shown in Fig. 7. Large numbers of similar types of moulding boxes are in regular use.

Damping Capacity.—This property is regarded as the capacity of a material to absorb vibrational energy and change it into another less harmful form—e.g., heat, when it can be dissipated. Magnesium alloys have a high damping capacity which is particularly useful in preventing vibrations

to fatigue, but, in common with other engineering materials, are sensitive to the effects of notches and design must be directed to the elimination of this disadvantage as much as possible. Notch sensitivity, besides meaning the obvious stress-raising effect induced by a notch, also includes sharp corners, burrs, etc., and defects in machining practice which are likely to lead to fatigue and consequent failure; some indication of what is meant is shown in Fig. 8. Stress concentration effects are known to adversely effect magnesium products, and while all efforts should be made to reduce or eliminate the various causes referred to above the general design of the part as a whole must be so constructed that no dangerous concentration of stress is likely to occur.

This should be axiomatic for all good engineering design and designers are usually well aware that when castings are under consideration, provision of adequate fillets, rounding of sharp internal corners, beading of holes, elimination of sudden changes of section, etc., must be allowed for in the design. When dealing with magnesium, the importance of these safeguards should be emphasised and a symmetrical outline should be aimed at.

The conception of the modern and efficient portable compressor unit, an example of which is shown in Fig. 9, has been aided by the inclusion of magnesium castings in its design and once again unnecessary weight has been dispensed with resulting in a product of high merit. Fig. 9b shows a group of these compressor castings

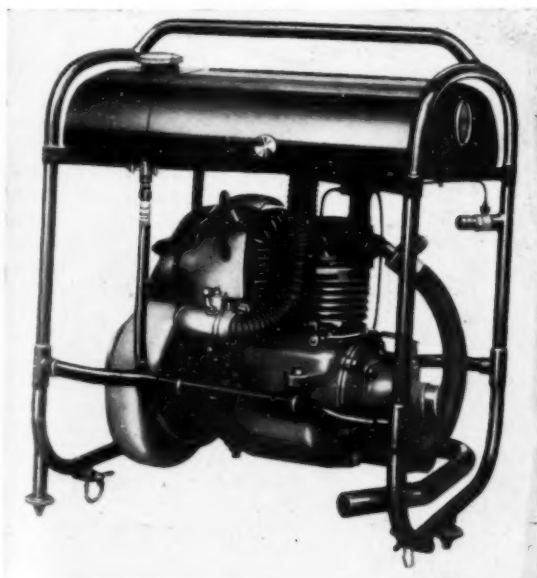


Fig. 9a.—The Hymatic compressor incorporating magnesium castings

Castings by Birmingham Aluminium Castings (1903) Co., Ltd.



Fig. 9b.—Fully machined Elektron castings for compressors awaiting collection after chromating.

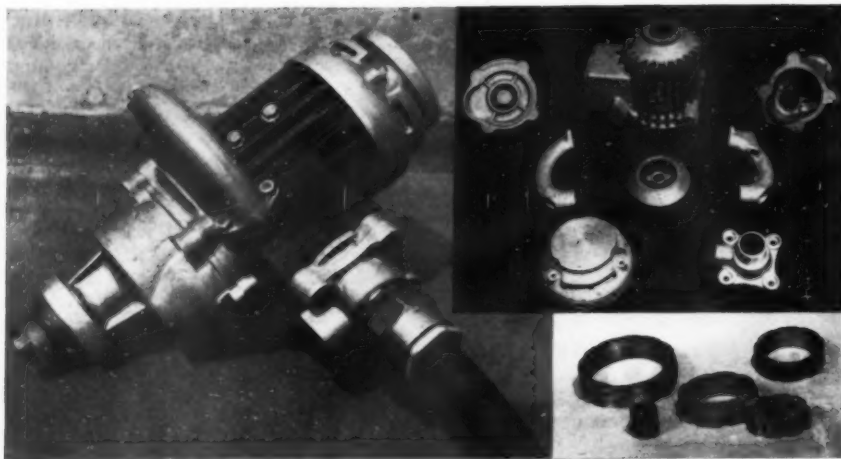


Fig. 10a.—Pneumatic coal drill using 10 Elektron castings, with typical inserts. Castings by Birmingham Aluminium Castings (1903) Co., Ltd.

Courtesy of Consolidated Pneumatic Co., Ltd.

awaiting assembly after final machining and R.A.E. chromating.

Bearing Properties and Hardness.—The maximum Brinell hardness for magnesium alloys in the fully-aged condition is about 85. However, their structure is such that they can be used successfully for bearings for light loads and at normal temperatures. Some examples of these applications can be found in aero-engine cam-shaft bearings, small electric motors and the like. Where heavy duty is involved it is recommended that bearing liners or cast-in inserts should be applied. In the case of cast-in inserts it is important that steps should be taken to give good "keying" facilities. Fig. 10 shows typical castings with steel inserts which are to-day making a significant contribution to the national economy.

It may be mentioned that in addition to the example illustrated many applications of this kind have been put to good use, road drills, pneumatic hammers and many types of manually operated machine can be cited.

Dimensional Change at Normal and Elevated Temperatures.—In common with other cast materials, dimensional changes do occur in magnesium castings and if the application is one demanding a high degree of permanent accuracy it is necessary that certain conditions should be observed. (See also section on machining). The reasons which may bring about these dimensional changes are: (a) Release of internal casting stresses causing actual distortion; (b) metallurgical changes in the structure causing growth of the part to an extent of some few 1/10 thous./

in.; and (c) creep which, although a function of sustained stress and temperature, is only of real importance with high temperature applications for which the usual Elektron alloys are not suited; perseverance has yielded good results with alloys containing cerium and attention is directed to work on this development.⁷

The release of casting stresses is easily brought about by the simple 4 hours annealing treatment described in a previous article; this effectively prevents distortion from occurring and largely nullifies growth effects. It is probably advisable to comment further

better than iron and steel, the passage of the years being revealed by a superficial loose layer of magnesium oxide; the strength of the underlying material is unimpaired as no inter-crystalline corrosion occurs.

The Elektron brakeshoes illustrated in Fig. 11 were made in 1939 and were

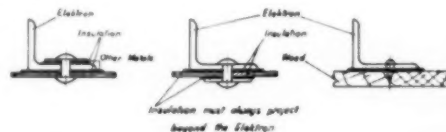
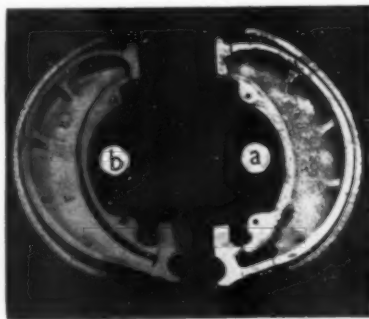


Fig. 12.—Riveted connections between magnesium and other materials. From "Technology of Magnesium and its Alloys," by Beck.

⁷ Magnesium-cerium-zirconium alloys. Properties at elevated temperatures. A. J. Murphy, M.Sc. and R. J. M. Payne, B.Sc. *Inst. Metals*, Paper 1039, November, 1946.



Courtesy of T. F. Blumfield, Ltd.

Fig. 11.—Motor-cycle brakeshoes in Elektron after seven years storage without protection: (a) As received; (b) after cleaning.

Castings by Birmingham Aluminium Castings (1903) Co., Ltd.

prevented from being used by the war; since that date they have been stored without any specific protection and their condition is a remarkable tribute to the corrosion resistance of the magnesium alloys. In general the corrosion characteristics of the normal magnesium alloys are as follows:—The material cannot resist seawater and salt solutions and, except for chromic acid, boric acid and hydrofluoric acid, all acids and most of their salts attack the metal in some degree, special mention should be made here of acidic vapours likely to be evolved from unseasoned timber—i.e., from packing cases and the like, which will also attack the material. Alkaline solutions, however, do not cause any attack—not even caustic soda (unless very strong and hot and contamination by chlorides is suspected in such cases). It must be realised that apart from marine conditions, strong acids or

alkalies pertain to chemical engineering conditions, which play havoc with most materials, and that for ordinary atmospheres magnesium will stand the test. When magnesium is joined to other metals, however, a galvanic cell is likely to be produced especially under moist conditions and efficient protection must be provided at each contact, examples of which are shown in Fig. 12, all designs should be vetted to see that no moisture traps occur. Magnesium alloys, of course, are not exceptional in this respect, it applies to other metals and alloys.

Whilst the above will form a good basis for comparison it must not be forgotten that all castings have a protective dip before despatch and should also be redipped after machining. The dip provides an excellent paint base, priming being done with a coat of zinc chromate after which various paints, laquers or low temperature enamels can be applied to suit varied applications. A useful booklet dealing with this aspect can be obtained

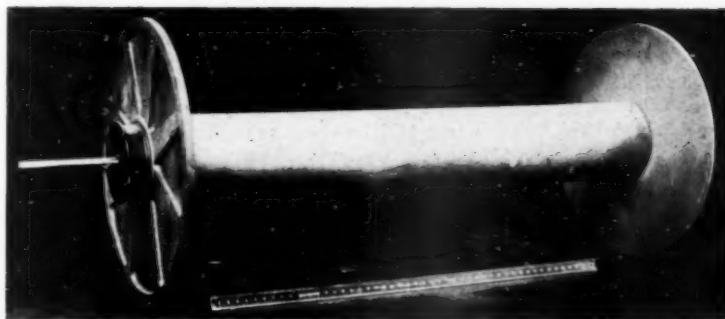


Fig. 15.—Textile warping beam in Elektron.
Castings by Sterling Metals Ltd.

on request from F. A. Hughes & Co., Ltd.⁸

Machining

"Truly phenomenal" is the general term that describes the machining

⁸ Some notes on the properties and surface treatment of magnesium alloys. F. A. Hughes & Co., Ltd.

capabilities of Elektron magnesium alloys and the ease and speed at which this operation can be performed plays a significant economic part in the use of the material. Some measure of the value this property yields is gained from the statement made by an

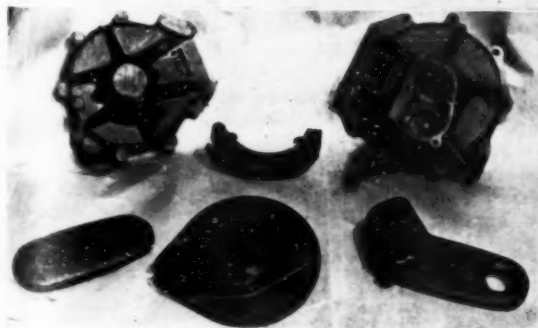
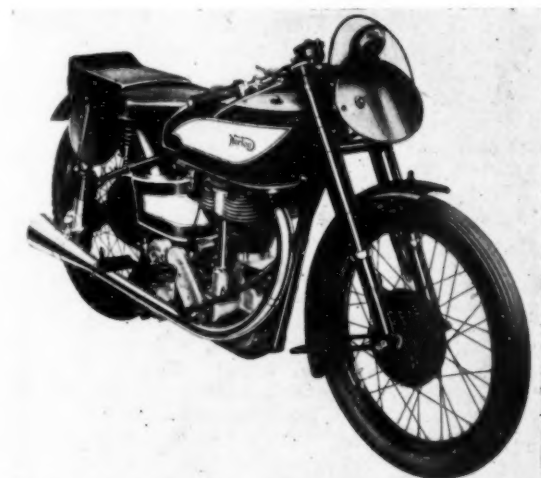
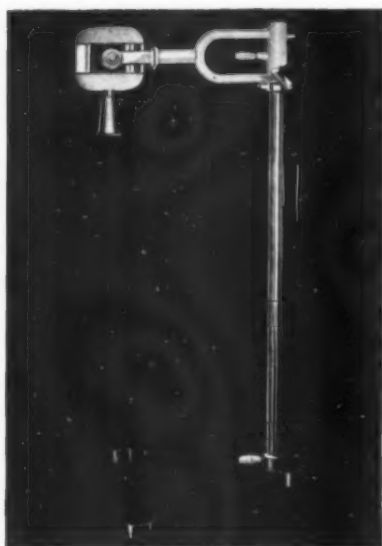


Fig. 13.—The Continental motor cycle—Model 30, Max type international machine with group of Elektron castings used in it.



Fig. 14.—The Ferguson tractor with one of the Elektron incorporated in it. The main magnesium casting, weighing about 56 lbs. is not shown.



Courtesy of General Radiological Co., Ltd.

Fig. 16.—Hospital X-ray apparatus utilising Elektron castings.
Castings by Birmingham Aluminium Castings (1903) Co., Ltd.

American firm during the war that they would require double their machine tools shop space to machine aluminium wheels which threatened to supersede magnesium alloy during the acute shortage period. Other data includes the facts that tool life is increased and less power is required to machine magnesium alloys. It is essential to take advantage of these qualities to get the full value from the use of the material; a calculated saving of 50% in machining costs compared with cast iron has been claimed. Extensive directions on the proper means of machining this material have been published, and briefly the following applies: (a) Machining speeds are high (Beck quotes 1,640–6,560 ft./min. for turning operations); (b) cuts are best kept heavy, but fine finishing cuts can be and are regularly performed; (c) a condition bearing on the previous statement is that tools must be kept sharp, and angles set to prevent any possibility of rubbing against the work; (d) the operation is very satisfactorily carried out dry, the coolant being compressed air directed on to the junction of the work and the tool, however if speeds are very high and some fines are likely to be generated the use of a cutting fluid, specially developed for magnesium work is desirable, its function being to cool the work and "drown" fine particles of metal which are a potential source of fire. Particular stress must be laid

upon the necessity to keep the work cool for magnesium has a high coefficient of thermal expansion and low-heat capacity which together act to dimensionally distort the piece being cut; also the low modulus of magnesium allows of distortion during clamping of the work in position, notice of these points is important to maintain dimensional accuracy.

Fire Hazard

This trouble exists in proportion to the lack of knowledge pertaining to the handling of the material, its abolition is certain if precise information and the "know how" is sought from the right people, the suppliers and founders who will gladly assist. Solid magnesium does not burn⁹ and if the correct machining directions are followed positively no fire hazard exists, however, the risk can be minimised by preventing the accumulation of chips around the machine tool and storing them in metal drums.

Additional Applications

Further examples of the versatility of Elektron magnesium are shown in Fig. 13, which are castings fitted to the high-speed motor cycles illustrated. Fig. 14 illustrates the application of magnesium castings to agricultural tractors. These machines are being manufactured in large numbers and are already helping to alleviate the world food shortage. Their burden is considerably lightened by the use of magnesium alloys, by means of which more power is made available for larger and more efficient cultivator tools.

Future Prospects

Engineers are indeed fortunate that magnesium alloys are available to them in abundance and that the delivery position for castings is immediate or at least better than most other commodities purchasable (assuming patterns available). The potential markets open to magnesium castings in the future are many and varied, the most important being transport. A logical development of the aircraft wheel is the application of magnesium to road wheels for vehicles of all types; the material is admirably suited to absorb road shocks and would considerably reduce unsprung weight. The number of magnesium castings and fitments that can be used by both steam and electric railway traction is immense, and now is the time to do it when so much rebuilding has to be undertaken. The private car and

⁹ Fire-fighting trials on magnesium-base alloys. *Engineering*, November 22nd, 1946.

electric road vehicle in particular are new markets which are surely waiting; a list enumerating all possibilities in these spheres would be tiresome, but engineers have only to review their designs to take the opportunity to substitute magnesium. Is the job easily portable? Does it require lifting? Is it a reciprocating part? Does it have to overcome inertia? Magnesium answers these questions. Portable tools, machine parts, textile machinery (see Fig. 15) are but a few additional examples of the future applications of magnesium castings and from a national point of view it should be remembered that this material is entirely "home made," the importance of this factor to-day cannot be overestimated.

Acknowledgement

The author tenders thanks to the directors of the Birmingham Aluminium Castings (1903) Co., Ltd. for their kind permission to publish this and previous articles in the series and wishes to record his appreciation to the staffs of Messrs. F. A. Hughes & Co., Ltd., Sterling Metals, Ltd., and Birmal, Ltd. for their unstinted help in preparing them.

Estimation of the Composition of Basic Open-Hearth Slags by means of Slag Cakes

By HOLGER PETTERSSON

THE possibility of estimating the composition of basic open-hearth slags from the appearance of slag cakes has been examined. A lot of slag samples have been collected from different works. They have been analysed and the appearance of the cakes has been studied. This examination has made it possible to discuss the influence of certain factors on the appearance of the top and bottom surface and the fracture of a slag cake.

The connection between the appearance of a slag cake and its chemical composition is described. In this description slags are divided into different groups of basicity. A distinction is also made between slags with low and normal contents of FeO and MnO, and slags with high contents of those oxides.

The accuracy of the basicity estimation has been found to be good, the error seldom exceeding 10%. The FeO-content seems to be more difficult to estimate. However, it can be done with a fair accuracy with certain types of slag.

From *Jernk. Annal.*, 1946, **130**, 678–701.

The British Iron and Steel Industry

Increasing Facilities for Production, Research and Development

The object of the iron and steel industry in this country is to increase the production of better qualities of steel at equal or less cost than anywhere else in the world. The high technical position of British steel in the past is unquestionable, but the diversion of research facilities to immediate war problems caused the industry to fall behind somewhat, and strenuous efforts are now being made to make up the leeway and restore the position. A brief outline is given of some of the steps taken to increase production facilities and to exploit scientific knowledge with this object.

ONLY hard work will enable manufacturers to make and sell British products in a competitive world, but increased production as well as advances in engineering science and practice depend upon the availability and quality of structural materials and upon a plentiful supply of fuel and power. Of the many structural materials involved in these products, steel plays a vital part. Indeed, it can be said that, as far as Great Britain is concerned, her economic survival in world trade depends, in no small degree, upon the efforts being made to increase supplies of steel of the right quality. At present, demands far exceed supplies, although the steel industry is making valiant efforts to relieve the position and is giving an output as high as plant capacities and available fuel will permit. The ordinary consumer will continue to experience an acute shortage until the fuel position is relieved and production capacity has been increased. The shortage of steel for normal commercial products is intensified by the imposition of priorities accorded to certain items of basic industrial equipment, for instance, equipment for electricity generation, mining, gas undertakings, coal-oil conversions, railway freight traffic and the industrial development of atomic energy. It will be noted that these preferences are designed to augment existing plant and equipment so that industry generally will be able to advance as new or modified basic equipment is put into operation. In addition to hard work necessary to increase production, there is the need for progressive improvement in quality of British products and for the introduction of new products, which will depend, in a large measure, upon the exploitation of scientific knowledge. As far as the steel industry is concerned it can be said that increased production facilities, coupled with the utmost of resources in research and development are the main contributing factors which will ultimately restore equilibrium between supply and demand. It is of interest to consider briefly what is being done in these two directions for British steel.

Research in the Industry

The high technical position of British steel in the last century is unquestionable, and arose through the enterprise of British people, who took advantage of this country's good natural resources to meet the great demand of an expanding industry. The high reputation of British steel still persists throughout the world. The early part of the present century saw the great expansion of the American steel industry, with which, at first perhaps, this country failed to keep pace, but so great an advance was made in the ten years before the recent war that this leeway was almost made up. The war

years, however, with the consequent standstill of plant building and the diversion of research facilities to immediate war problems, made the technical position of the steel industry again fall behind. It should not be forgotten that, during the war, Britain directed her energies to whatever would best serve the common cause, without thought for her economic future, and such weaknesses as there may be in the steel industry are due almost entirely to that cause. To-day the object is quite clear—namely, to produce in this country better qualities of steel at equal or less cost than anywhere else in the world, and to be the first to introduce new steels and new processes, just as this country is generally the first to discover them. Only by achieving this can the industry make its expected contribution to the prosperity and happiness of the people of this country.

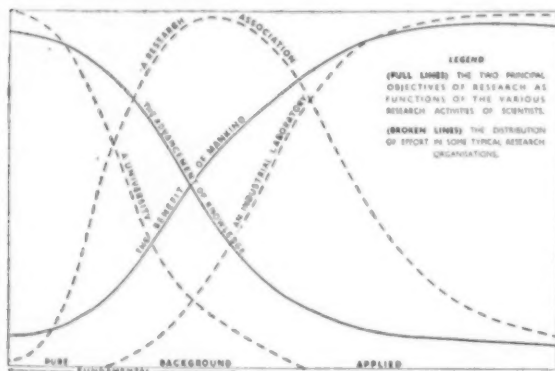
Fortunately, on the research side, as well as on other sides, there is a strong basic organisation, and in outlining some aspects of the development of the research organisation in the industry, it will be found that it falls in three parts—competitive research in special products, co-operative research and academic research.

Most of the major steel makers of this country have well-equipped and well-staffed research and development laboratories, some of which are outstanding. Their natural pre-war expansion, held up during the war, is in full swing again, and before long their total size will be double the 1939 level. The importance of works research laboratories striving to maintain the competitive position of the various products of the industry remains unchallenged even in this present revolutionary age, in which co-operation has become so popular. On the academic side also their is great strength, although here, as in many other parts, there is the need for considerable expansion.

Gradually it is being appreciated that, to maintain a progressive position, the British steel industry must make a steady and persistent study of the many problems that continuously arise and, in more recent years, teamwork in research and development has been growing fast in the form of co-operative research. Some indication of this growth is shown in the increased expenditure of the research associations from £300,000 to well over £1 million a year in the last ten years.

Co-operation in the iron and steel is not new, it goes back to the founding of the Iron and Steel Institute and of many local metallurgical and engineering societies in the last century. The main object of these associations was to provide a means for members to meet and discuss their experiences, although the advantages were somewhat limited by the competitive atmosphere of the times. However, it was not until 1917 that the Iron

and Steel Institute took the initiative and set up five committees to investigate certain problems which were troubling the industry as a whole at that time. Four of these committees ceased to exist in 1921. But soon after the 1914-1918 war the executives in the steel industry set up the National Federation of Iron and Steel Manufacturers to tackle some of their major common problems. It was soon realised that the common commercial problems were intimately related to their common technical problems and money was provided to carry out research. Further developments followed and the National Federation of Iron and Steel Manufacturers became the British Iron and Steel Federation and the Fuel Economy Committee and research group, that had previously been formed, became the Technical Department of the Federation under the Iron and Steel Industrial Research Council. The Department of Scientific and Industrial Research gave notable financial and other assistance and joint committees were set up with the Iron and Steel Institute in many important fields of research. Towards the latter part of the recent war, on the advice of the Department of Scientific and Industrial Research and in consultation with the Iron and Steel Institute, the Federation set up an autonomous body, the British Iron and Steel Research Association, the Federation undertaking, on behalf of the industry, the provision of the basic funds. The research activities of the Industrial Research Council and of the Joint Committees of the Iron and Steel Institute, together with those of another small but active party in South Wales are now merged in this research organisation.



The main function of the British Iron and Steel Research Association of course is to carry out research, but it is concerned primarily with background or objective research and with new techniques, processes, etc., of common interest. Support will be given to carry out fundamental research in the Universities rather than do such work in the Association's laboratories, unless there are special reasons to the contrary. The Association provides for a considerable extension of co-operative research, but its activities will tend to increase the need for research laboratories in firms' works; indeed, since the formation of the new Association, work's research laboratories have increased and are better equipped and staffed than formerly. Sir Charles Goodeve, O.B.E., D.Sc., F.R.S., Director of the British Iron and Steel Research Association in describing the lines on which the Association is built, before the Sheffield Society of Engineers and Metallurgists, used the graph,

reproduced here, to indicate the objectives and distribution of research in the industry. It will be seen that there is no sharp line between the work of the universities, the Association and work's research laboratories.

Reconstruction to Increase Production

The plan to modernise the iron and steel industry with a view to increased and more economic production has been in operation for some time. As mentioned in a previous issue of this journal the expenditure contemplated over a period of about five years is nearly £200 million, covering the needs of the various districts. Some brief information concerning the work done or in progress connected with this plan will indicate the progress so far achieved.

At Steel, Peach and Tozer's, the first major step towards this firm's modernisation plans was the installation in 1944 of the new cogging mill. This mill, with a 42-in. roll diameter and 7 ft. 6½ in. length of barrel, is dealing with a weekly input of 14,000 to 15,000 tons, probably the highest of any cogging mill in the country. The resulting increase in production has been of the order of 15-20%, together with greater reliability. An increase in steel production is also in course of being effected, by means of improved charging and handling equipment, increased installation of water cooling for vulnerable parts of the open-hearth furnaces and by ultimate conversion of 8 out of 21 furnaces to oil firing and 2 to coal tar oil firing. Four have already been converted. Total ingot production will be increased by about 10% by these means, and, with additional improvements to be made, a further increase in capacity of about 10%, bringing the total to nearly 800,000 tons per annum is expected.

The main item of reconstruction at these works at the present time is the £250,000 reorganisation of the wheel mill which is designed to increase the firm's output of railway material by 30%. Almost all existing machinery for the manufacture of railway wheels is to be replaced, much of it in new buildings. New plant to be installed includes a 6,000-ton forging press by Davy and United Engineering Co., Ltd.; a vertical type wheel rolling mill with its ancillaries; reheating furnaces and improved handling arrangements. On the tyre rolling side a new heat-treatment plant has been installed with new coke-oven gas-fired furnaces to cope with the increased capacity. These new furnaces comprise three rotary and three static hearth installations of the circular-vertical type.

In addition to various installations, a number of projects are in hand having the general object of saving fuel and increasing efficiency. The small bar and section mill at these works, for example, are to be electrified, and increased stock accommodation is being provided in the finishing department, while the railway spring department has been laid out anew and mechanised. The engineering shops are in course of re-building and more modern maintenance machinery is being installed.

Samuel Fox and Co., Ltd. will have spent well over £1 million, during the three years following the end of the war, on plant improvements and developments. This total is made up of a large number of items which contribute considerably to the modernisation and reconstruction of all departments. These items include the conversion of three basic open-hearth furnaces from producer gas to crude oil firing. The billet mill is being equipped with an additional Priest continuous soaker

furnace with a throughput of 15 tons per hour, fired by a Morgan gas producer. Accuracy of temperature at the rolls is being controlled by the installation of a high-speed optical recording pyrometer.

The stainless sheet production plant is undergoing alteration, with an increase in the furnace capacity of the sheet mill by 25%, and the installation of a number of polishing machines; these include a battery of 12 ft. and 6 ft. Craven polishers, and a Mattison machine. The cold-rolled department is being reorganised. A new shop has been in operation for about 12 months, and the colour scheme adopted in this shop is of exceptional interest. The bulk of the cold-rolling plant is being concentrated in the new shop, leaving the old shop for the concentration of bright-bar manufacturing plant. The new plant installed in the cold-rolled strip department includes two Robertson 4-high mills capable of operating at 1,000/1,500 ft./min. The output of these mills is used for high grade carbon steel strip, to tolerances of 0.0002 in., for clock and instrument main-springs, feeler gauges and razor blades. The heat-treatment plant for the cold-rolled strip department includes, at present, 22 GEC pit-type electric furnaces for bright annealing. The first of these was installed at the beginning of the war, but the majority have been added since 1945. Five more similar furnaces are to be installed shortly.

An interesting installation is six hardening and tempering furnaces now in operation for the treatment of clock and instrument main-spring material. Each unit deals with about one ton per week; they are designed for extremely accurate control of temperature to meet the most exacting specifications. It is expected that 12 such units will shortly be in operation.

Another important development at these works may be briefly summarised. Ten years ago, the laminated spring plant was converted to full mechanical continuous line production, incorporating the latest developments of the time. A further re-organisation scheme is now in hand, involving the installation of new plant, including forced air circulation furnaces, highly specialised machine tools for machining the spring leaves, shot peening plant, aluminium sprays plant, etc. A new building is being erected to provide the necessary space for these developments, and a smaller plant is being installed to deal with the manufacture of oddment orders on continuous mechanised lines.

Apart from the developments at their Stocksbridge works, Samuel Fox and Company have also up-to-date schemes in the small Sheffield works they acquired from Messrs. Darwin's Ltd. in 1945. Here there is an output of some 160 tons per week of strip and a small tonnage of fine wire. This strip department, obtaining its raw material from the adjacent United Strip and Bar Mills, is producing mostly tube strip and similar qualities in widths up to 10 in. wide, and in thicknesses down to 0.005 in. There are two Bliss 4-high mills, two Bliss 2-high mills and a Robertson 10½ in. × 10 in. mill, with pickling and slitting plant. The continuous pickling plant for descaling the hot rolled strip is of interest. It consists of an uncoiler, scale breaking machine, acid tank, water spray, drying rolls, oiling roll and coiler, designed to process 10 strips, 3¼ in. wide or wider strips in proportion.

At the group of works belonging to Messrs. Dorman Long, there is in progress a number of developments designed to benefit production from the earliest raw

material stage right through to the fabricated product for which they are famous. In connection with the latter, the main constructional department is being extended in order to facilitate the handling of the longer units which modern construction demand. Only two new machines are to be installed, both edge planers, though there is to be considerable re-arrangement of existing plant in order to give extra space for longer units.

A major development, which is in progress at the Cleveland Works, is an ore preparation plant designed to handle 2½ million tons of ore per year and sinter 350,000 tons. The work on the screening and crusher house has been held up by bad weather as has progress on civil engineering work generally, but it is hoped that production will start about a year from now. The general intention is to concentrate the discharge of ore for the whole group of works at one point. Although this will mean an added haulage to the Redcar and Acklam Works, this will be offset by the use of thoroughly up-to-date machinery made possible by the volume of materials handled. As the main consumption point is at the Cleveland Works, the unloading will take place there and the ore will be conveyed to the stock piles by electric locomotive propulsion. Ore for the Cleveland Works will pass through the preparation plant and thence by belt conveyors to the blast furnaces. The effect on Cleveland of the use of a large proportion of prepared ore is expected to be a substantial improvement in output and an appreciable drop in fuel consumption per ton.

In this connection, it should be mentioned that the new unloading arrangements are expected to reduce the time needed for unloading ships of reasonably large size from about five days to two days. This will be accomplished by the installation of transporter cranes which will be assisted by the job cranes at present used and the construction of a new berth and the improvement of existing berths.

There is one further development in progress at Dorman Long's Works which it is hoped to have completed by the end of this year and that is the construction of 4½ miles of private rail track between Cleveland and Redcar Works, linking also the Lackenby site where the new Universal Beam Mill and steelworks will ultimately be installed.

Modernisation schemes in hand at Consett Iron Works have a total cost of some £3,000,000. The first stage of the programme involves a large scale reorganisation of the energy balance of the whole works. In an integrated plant such as Consett, this is a considerable undertaking. Two new batteries of coke ovens are being constructed, a second new blast furnace will shortly be blown in and the building of another begun, and a very large new boiler plant and power house is being constructed. The net result will ultimately be that the only fuel to be brought to the works from outside will be: Coking coal to the coke ovens; and low grade fuel to the boiler plant.

The ore preparation plant at Consett was installed in 1943, and can crush and screen up to about 400 tons per hour. The sintering plant, consisting of 13 stands with 2½ to 3 ton pans, can produce about 3,500 tons of sinter per week. All the ore used passes through the preparation plant from which it is conveyed by belt to the furnace bunkers.

The coke ovens plant at present in operation, com-

prises a battery of 60 Wilputte ovens, capable of carbonising 7,000 tons of coal per week. These ovens some years ago were well before their time in design, and remain a quite efficient plant by modern standards. They were, indeed, the first silica walled ovens to be installed in the United Kingdom. Their capacity is to be supplemented by two batteries of Becker ovens, which will carbonise an additional 8,000 tons of coal weekly in total of 54 large ovens. The new coke oven batteries and bunkers are in process of construction, and it is hoped that they will be in operation by the autumn of this year.

The blast-furnace plant at present in operation consist of two furnaces, No. 8 and No. 2. The former, at present producing hematite iron, is comparatively small by modern standards having an output of 1800 tons per week for consumption of about 22 cwt. of coke per ton of iron. This furnace is due for dismantling when the new No. 3 is blown in this summer, to make way for the third modern blast furnace to be installed. No. 2 was blown in during 1943, and is a thoroughly up-to-date plant having an output of 4,500 tons per week using imported ore, which passes through the preparation plant, at a consumption of 17 cwt. coke per ton of iron.

This furnace is equipped with a McGee distributor top and fully automatic charging arrangements with a central control panel. The present blast-furnace gas wet cleaning plant is being supplemented by Lodge Cottrell electrostatic precipitation plant.

The No. 3 furnace shortly to be blown in is slightly larger than No. 2, with an estimated output of 5,000 tons per week. Apart from this they are substantially similar. As soon as the new furnace is operating successfully the old, hand-charged No. 8 furnace will come off, to be dismantled to make way for the third modern furnace, No. 1. The net result, pending the completion of No. 1 furnace in two years or more from now, will be a production of between 9,000 and 10,000 tons of pig iron per week in place of the 6,000 odd tons now being produced.

Extensions and reconstruction schemes now in hand at the Appleby-Frodingham works, Scunthorpe, of the United Steel Companies, Ltd. involve the expenditure of over £3,000,000. Their two main features are the reconstruction and electrification of the section rolling mills, and the replacement of the present Frodingham melting shop by the south melting shop now under construction. Both these schemes were approved two years ago, and it is hoped that the end of this year will see the completion of the melting shop project, and early 1948 the completion of the modernisation of the rolling mills. A logical extension to these alterations will later be the shutting down of the Frodingham blast furnaces, and the substitution for them of the new plant to be erected as extensions to the furnace plant brought into operation shortly before the war. Extension at the other end of the production cycle has already taken place, and the constructional department has a new bay erected and awaiting installation of cranes which will, when in full production, increase output by some 200 tons per week. As about half the work of this department comprises colliery material, this is a valuable contribution to the national effort at the present time.

The alterations to the rolling mill are in the nature of a major operation. The main considerations facing the designers were:—(a) The unique cooling bank with its battery of roller straightening machines has to be retained

in its present position; (b) the mill stands and roller tables of the old shop are placed too close together to permit the installation of modern equipment; (c) only the minimum interference with production could be permitted.

The number of mill stands will remain as at present, but will be electrically driven by two Metrovick motors of 5,500 and 5,000 h.p. continuous rating respectively, which will give a choice of driving the roughing stands through the cogging mill or the finishing mill. The cogging mill itself is a new one, 42 in. \times 8 ft. 6 in., with side-guard manipulators, an electrically-driven bloom shears, roller tables and the necessary billet handling equipment. The existing 32 in. roughing and finishing mills will be moved to the new positions, new roller tables, etc., being provided where necessary. The new layout is designed to maintain output from the cogging mill at between 5,000 and 5,500 tons per week, and from the 32 in. mill at between 3,500 and 4,000 tons per week.

A corollary to the alterations to the section mill is the erection of the new south melting shop, to replace the present Frodingham melting shop, which is being built on a new site adjacent to the South Ironworks. The furnaces are to be fired with a mixture of coke-oven gas and blast-furnace gas made available by the electrification of the Frodingham section mills.

This will eliminate the need for the producer gas plant at Frodingham which consumes over 800 tons per week of coal, though these furnaces now fired by producer gas at Appleby will have to continue on this supply until the blast furnace capacity at the South Ironworks is ultimately increased. Supplementary liquid fuel-firing equipment is being provided at both melting shops.

At present there are two blast furnaces at South Ironworks, both blown in during 1939, 95 ft. high with 22 ft. hearths and 3,000 tons per week output, to which two further furnaces will be added having 25 ft. hearths and 3,500 tons per week output. The ore crushing plant, however, will be adequate for the projected capacity, though the sintering plant will have to be increased by 50% to produce 3,000 tons per day. The present coke-oven capacity is a battery of 66 Kopper ovens with an output of 6,000 tons per week of blast-furnace coke, which it is planned to double.

The new open-hearth melting shop is to be of approximately equal capacity to the Frodingham melting shop, with an output of some 200,000 tons per year of ingots, but the steel will be melted in two large tilting furnaces instead of the four small tilting furnaces at Frodingham. The two new furnaces will be of 300 tons capacity, electrically tilted, with electrically-operated door and reversing gears, the hearths being approximately 650 sq. ft. at sill level. Hot iron will be brought from the adjacent ironworks (about 75% hot metal will be used and 25% of own mill scrap). There will be a 600-ton mixer with a hearth area of about 860 sq. ft. at sill level, also electrically tilted. A portion to the stage in front of the mixer is designed to slide into ambush, to enable 60-ton hot metal transfer ladles to be lowered into the valve pit so that they can be filled while they are still suspended from the 100-ton cranes, with two of which the furnace bay is equipped. The molten mixer iron will be fed to the furnaces down removable chutes through the charging doors. There will be two 4-ton chargers of the revolving ground type.

[Continued on page 160]

Some Effects of Welding Heating Cycles on Heat- and Corrosion-Resisting Steels

By H. Bull

Brown Bayley's Steel Works, Ltd.

Not all the difficulties associated with the welding of heat- and corrosion-resisting steels occur in the fused metal at the joint. The author, at a recent meeting of the North Eastern (Tyneside) Branch of the Institute of Welding, described the three main types of steels used, and discussed some of the effects of the welding heat on material adjacent to the weld. The effects of the welding heat are considered with respect to the consequent changes in structure, corrosion-resistance, mechanical properties, etc., and some account is given of the metallurgical steps taken to overcome them.

IT is generally agreed that there are few elements yet to be discovered, and, in so far as this applies to metals, it is perhaps a good thing, because with such as are known the number of alloys which accrue is almost legion. To the uninitiated, the subject must appear bewildering, and perhaps only a little less so to a welder; even so, the welder has long since passed the stage of joining two pieces of iron in a smith's hearth, and necessarily so when stainless and heat-resisting alloy steels require joining or welding, because that process is distinguished by being about the only one which cannot be used. All other methods present few difficulties when reasonable precautions are taken. This discussion, however, is not concerned with the actual welding but with its effects, usually adjacent to the welded joint.

In considering the effect of welding on these materials it will be convenient to view the field covered by them in the more conventional way. Heat- and corrosion-resisting steels are usually divided into three main groups known as the martensitic stainless steels, the ferritic stainless steels, and the austenitic stainless and heat-resisting steels and it is proposed to deal with them under these headings.

Martensitic Stainless Steels

The martensitic stainless steels contain 12 to 14% chromium, the remainder being mainly iron. The carbon may vary but does not usually exceed 0.40%.

These steels can be hardened and tempered. The middle range of carbon 0.18 to 0.25% is best for this purpose and when fully tempered these steels have a tensile strength of about 50 tons per sq. in. and are tough. The steels with the higher carbons and in the fully hardened condition are hard enough for ball

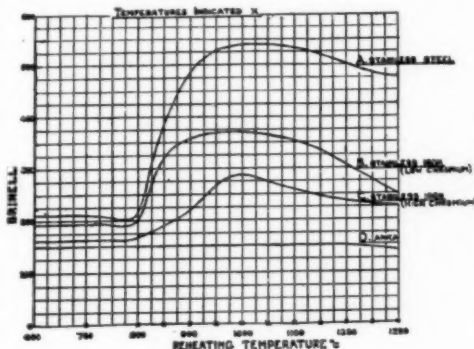


Fig. 1

Fig. 1.—Hardness of stainless steels air-cooled from temperatures indicated by X. Fig. 4.—Showing the losses in weight of cylinders in various conditions of heat-treatment after immersion in 3.5% solution of sea salt for 52 weeks.

bearings and domestic cutlery—which will cut if the user takes the trouble to sharpen it. Steels of the lowest carbons in this range (up to 0.12%) are called stainless irons, commercially introduced about 1920,



Fig. 2.

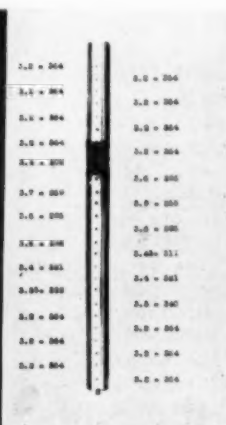


Fig. 3.

Fig. 2.—Corrosion at part of knife softened by heating for welding or brazing handle to hardened blade. Fig. 3.—Corrosion test confirming the reduced resistance of softened material.

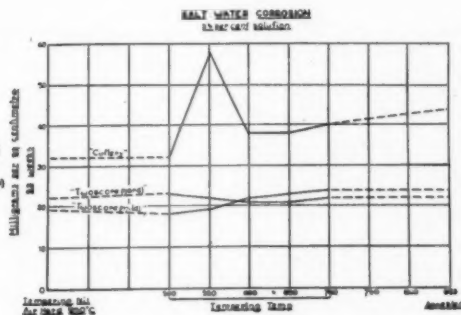


Fig. 4

Fig. 1.—Hardness of stainless steels air-cooled from temperatures indicated by X. Fig. 4.—Showing the losses in weight of cylinders in various conditions of heat-treatment after immersion in 3.5% solution of sea salt for 52 weeks.

for which many uses are found in engineering, notably as turbine blades.

The most notable modification of all the steels in this group is the addition of $\frac{1}{2}\%$ molybdenum which increases slightly the corrosion resistance.

To the welder, the chief disability of these materials is the hardness developed after cooling from high temperatures, and the precaution is therefore taken of pre-heating to 300–400°C. prior to welding, followed preferably by a reheating to 600–700°C. after the welded zone has cooled through the magnetic change (about 200°C.). The hardness developed in several types of stainless steels by air cooling from a range of temperatures is illustrated by Fig. 1.

The first of the martensitic steels (introduced by Brearley in 1912) is familiar as table cutlery. It was called "stainless" because when it was hardened and polished it was not stained in domestic use. When softened the corrosion resistance under similar conditions is lessened and an all too familiar sight on knives in hotels and restaurants is shown in Fig. 2.

The corrosion has occurred at a portion of the blade which was softened by the heating for welding or brazing the metal handle on to the previously hardened blade. Confirmation of this is shown in Fig. 3 which shows a corroded band and hardness measurements on a bar first softened along its whole length and then hardened at one end only before polishing and corroding in sea water for ten weeks. The quantitative effect of the reheating on the corrosion resistance is shown in Fig. 4. A sharp maximum in the rate of attack by sea water occurs in material reheated to 550°C. Consequently, softening a hard bar at one end or hardening a soft bar at one end, as will happen in welding, will result in bands less resistant to corrosion.

These earlier examples of corrosion, due to alteration of the properties of the steel by processing, led to searches for steel more resistant to corrosion, and many are available, but their development was prompted mainly by the desire to extend the uses of stainless and heat-resisting steel into spheres of greater corrosion or heat. A familiar example is the steel containing about 16% chromium and 2% nickel, which is in the martensitic class because hardening and tempering refine it and make it tough. Its main use is for aircraft parts built up from sheet and strip heat-treated as complete units after welding.

Ferritic Stainless Steels

This group contains upwards of 16% chromium, usually 16 or 20 or 27%, carbon contents often varying and increasing with the chromium content from 0.10 to 0.30%.

The use of steels of this type does not appear to have been developed in this country to the same extent as in America, probably because the austenitic type (referred to later) appeared to have advantages in fabricating processes. Economical advantage might accrue by increased use: initial costs should be less by saving nickel, and processing costs may be less because the physical properties are more nearly akin to those of mild steel, and fabrications would respond to the stress relieving temperatures (and furnaces) used for mild steel.

The main disadvantages are brittleness to a degree, which in some processes amounts to fragility, and increasing brittleness due to grain growth which occurs

at a red heat. Welding presents no difficulty, but the brittleness due to grain growth near the weld should be relieved where possible by heat treatment at 650–700°C. Held at 470–490°C., the higher chromium steels (27%) may become brittle by development of a second phase—sigma—which is hard, non-magnetic, and very brittle. This does not appear to be a bad risk in the writer's experience.

The main modification to this group has been by small additions of nitrogen, and a series of observations on the nine alloy steels shown in Table I was made to show the effect of this addition.

TABLE I.

Cast	C	Si	Mn	Cr	Ni	N
HF.1742 ..	0.03	0.29	0.48	16.5	0.10	0.029
HF.1743 ..	0.03	0.44	0.43	21.5	0.12	0.030
HF.1744 ..	0.03	0.45	0.51	26.3	0.16	0.032
HF.1745 ..	0.06	0.38	0.34	16.5	0.12	0.116
HF.1746 ..	0.05	0.46	0.42	21.6	0.10	0.126
HF.1747 ..	0.06	0.49	0.44	26.6	0.16	0.118
HF.1748 ..	0.05	0.36	0.28	16.7	0.10	0.197
HF.1749 ..	0.05	0.44	0.33	21.9	0.13	0.197
HF.1750 ..	0.07	0.56	0.34	26.7	0.16	0.216

Portions of each alloy ingot were rolled to $1\frac{1}{8}$ in. diameter bar. In this condition discs were cut, tested for hardness, and fractured longitudinally. A series of similar discs cut from each cast was reheated for 30 minutes at various temperatures from 700° to 1200°C., tested for hardness and fractured longitudinally. The resulting hardnesses are shown in Table II.

TABLE II.

Cast	Cr	N	As Rld.	Reheated (°C.)							
				700	750	800	850	900	1000	1100	1200
HF.1742	16.5	0.029	192	156	152	149	143	170	196	166	159
HF.1743	21.5	0.030	153	151	151	153	149	158	156	149	149
HF.1744	26.3	0.032	166	166	166	163	166	170	166	159	161
HF.1745	16.5	0.116	269	196	196	174	163	212	321	286	292
HF.1746	21.6	0.126	174	174	174	163	163	180	156	166	166
HF.1747	26.6	0.118	166	166	166	170	170	159	159	166	168
HF.1748	16.7	0.197	402	328	323	292	196	228	387	375	358
HF.1749	21.9	0.197	183	187	187	174	174	172	170	179	183
HF.1750	26.7	0.216	183	183	179	179	170	172	160	183	187

Difficulty was found in obtaining checking hardness figures from 900°C. on the 16% chromium steels, particularly the 0.1 and 0.2% nitrogen alloys. This is evidently due to this temperature being inside the solution range, and a small temperature increment therefore, has an appreciable effect on the hardness developed.

Within each nitrogen content group the alloy containing the lowest chromium (16%) is the hardest and the hardness of these 16% chromium alloys increases with increasing nitrogen contents, so that, whereas in the low nitrogen content group the 16% chromium alloy is only some 30 to 40 points Vickers hardness higher than the other two alloys, in the highest nitrogen content group the 16% chromium alloy is over 200 points harder on the Vickers scale. Apart from the three 16% chromium alloys, the reheating of the as-rolled materials at any temperature from 700° to 1200°C. has practically no effect on the hardness. In the case of the 16% chromium alloys tempering occurs, the effect of which is of course, dependent on the initial hardness, up to and including 850°C. At 900°C. partial rehardening occurs on all three steels and after heating at 1000°C. the hardnesses are not dissimilar from those

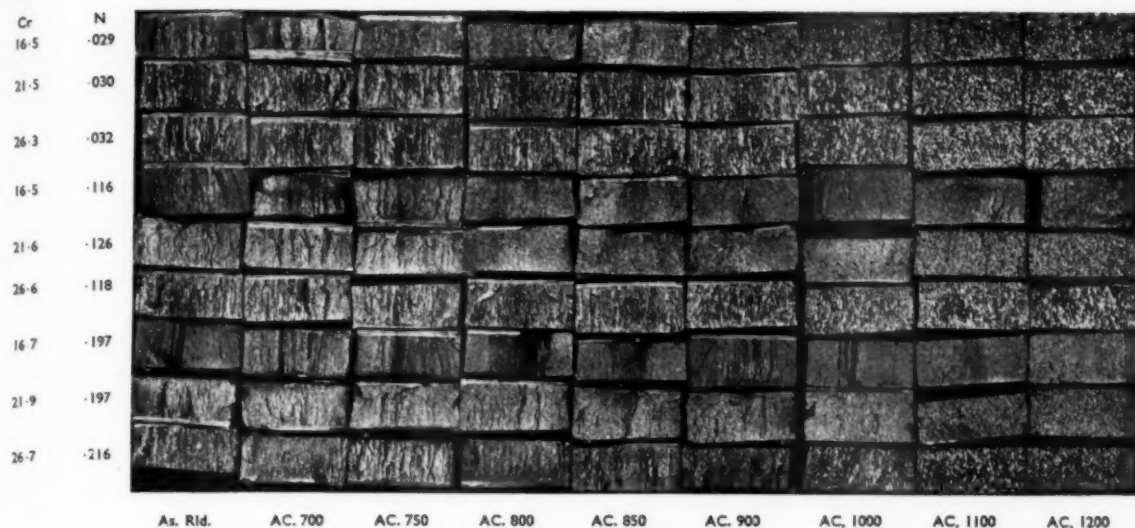


Fig. 5.—Fractures of samples showing the refining effect of nitrogen additions.

of the respective as rolled bars. Slight softening occurs after reheating to temperatures from 1000° to 1200° C.

The fractures obtained on the various samples, both as rolled and reheated to the several different temperatures, are shown collected in Fig. 5. The fractures are self explanatory, but they clearly show the marked refining effect of the nitrogen addition, particularly to the 16% chromium type. They also satisfactorily confirm the hardness values in that they indicate that recrystallisation begins to occur at 900° C. and is clearly apparent at 1000° C., at which temperature those alloys capable of hardening, i.e., the 16% chromium type, have assumed their maximum hardness.

The microstructures of all these pieces have been examined and, although there are many interesting features shown, the main observations to be made are that the hardenable nature of the 16% chromium

types is clearly shown in the structures and the general commencement of recrystallisation on reheating to 900° C. is quite definite.

In order to determine to what extent coarsened material will be refined by reheating, discs of all the

TABLE III.

Cast	Cr	N	AC. 1200° C. and reheated (° C.)					
			—	700	750	800	850	900
HF.1742 ..	16.5	0.029	166	159	166	163	143	156
HF.1743 ..	21.5	0.030	153	166	159	155	159	156
HF.1744 ..	26.3	0.032	170	170	170	170	170	163
HF.1745 ..	16.5	0.116	262	207	192	183	174	187
HF.1746 ..	21.6	0.126	170	179	179	174	174	174
HF.1747 ..	26.6	0.118	179	183	187	187	187	183
HF.1748 ..	16.7	0.197	351	235	217	207	192	217
HF.1749 ..	21.9	0.197	179	202	196	187	183	183
HF.1750 ..	26.7	0.216	196	196	196	202	196	192

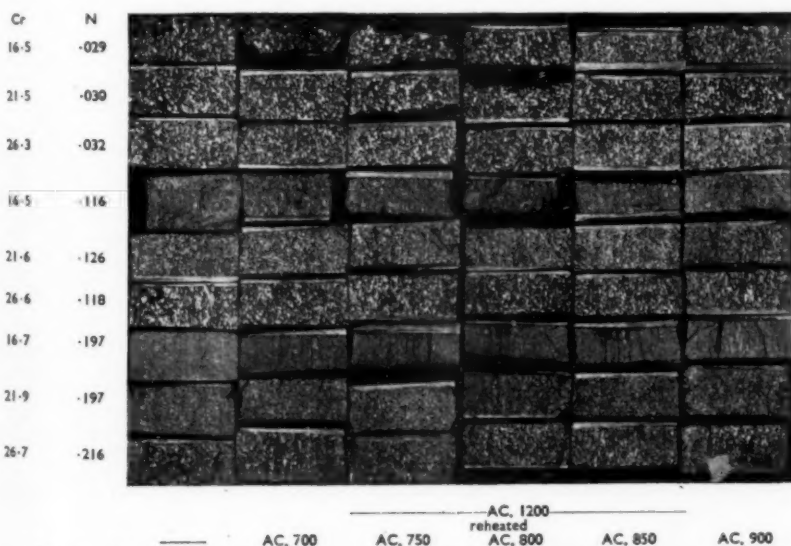


Fig. 6.—Fractures of samples showing the effect of reheating on the coarsened structure produced by heating to 1,200° C.

steels were coarsened by heating to 1200° C. followed by reheating to temperatures from 700° to 900° C. These discs were tested for hardness and fractured as previously. The hardnesses of these coarsened and reheated pieces are given in Table III.

As would be expected, the three hardenable steels (16% chromium) show a tempering effect up to 850° C., but the other materials show no significant change in hardness.

The fractures obtained on these coarsened and reheated samples are shown in Fig. 6. The fractures show clearly that the coarsened structure produced by heating to 1200° C. is not removed or refined by reheating, although the coarsened effect produced by the 1200° C. treatment varies considerably

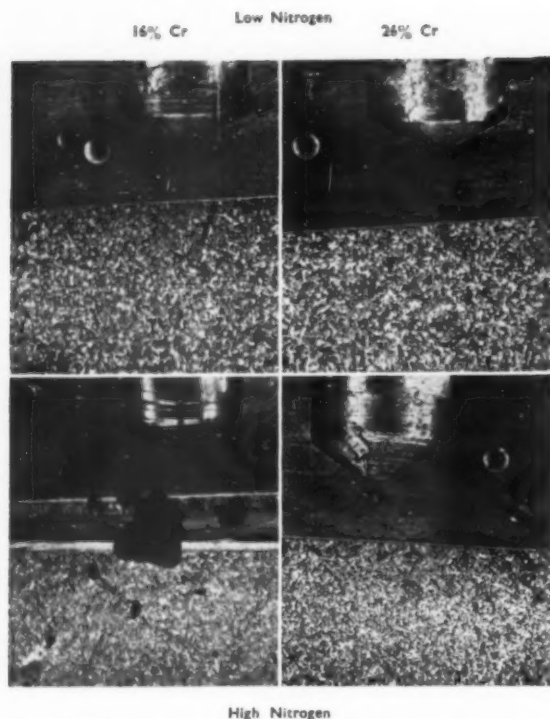


Fig. 7.—Cast samples of 16 and 26% chromium irons of low and high nitrogen content.

and is generally lowest within each group of different nitrogen contents in the 16% chromium steel. The grain growth produced in the 16% chromium steel of the two higher nitrogen groups is remarkably little, but even in the 21%, chromium does not appear excessive. The 26% chromium series coarsen appreciably irrespective of the nitrogen content.

Nitrogen may be regarded as an almost unavoidable constituent of any arc weld deposit and too much of it in a high chromium steel may cause unsoundness,

although the amount necessary to cause this varies somewhat according to the chromium content. Cast samples of 16 and 26% chromium irons, of low and high nitrogen, are shown in Fig. 7. The recommended amount to be added during steel making is not more than one-hundredth of the chromium content. Such an amount may be readily gathered from the air during the deposition of an arc welding rod containing 12 to 20% of chromium, and it will be appreciated from the details of the nitrogen-containing chromium irons already considered that absorption of nitrogen may produce high hardness in a weld made with a high chromium iron. That this may actually occur is shown in Fig. 8 which gives hardnesses obtained on mild steel and 14% chromium iron welds on chromium iron and mild steel. In the as-welded condition, the chromium steel welds give Vickers hardness values of 550 in the deposit metal. These values are unusually high, but may be explained by the analysis of the deposit metal. It was found to contain 0.19% of nitrogen, whereas the average nitrogen content of the welding rod core wire would be something of the order of 0.03%. Clearly then, core wires for arc welding rods should be substantially free from added nitrogen.

The Austenitic Stainless and Heat-Resisting Steels

In the twenty years or so which have elapsed since this type became generally available, development has been tremendous and to-day, by far the greatest tonnage of stainless heat resisting steel used is of this type. Many modifications have been made to the originally developed composition and the user or supplier may have to choose from 12% chromium/12% nickel, 15/10%, 18/8%, 25/14%, 25/30%, 15/35%, all of which may have added elements such as titanium or niobium to stabilise the carbides, or selenium or sulphur to make for easier machining. A further modification is by the addition of molybdenum or copper or both to increase resistance to corrosion. To this last can be added a similar but extended group of alloy steels containing cobalt and tungsten as well as the above-mentioned elements, including those which are used in

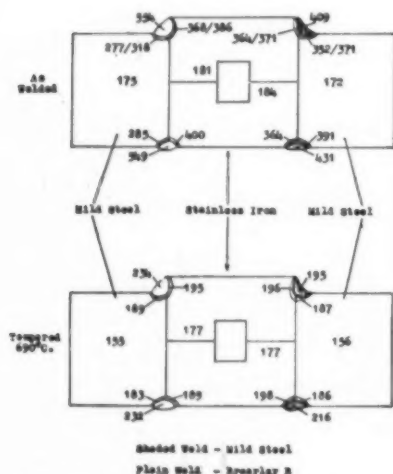


Fig. 8.—Showing the effect of the absorption of nitrogen in a weld made with a high chromium iron.

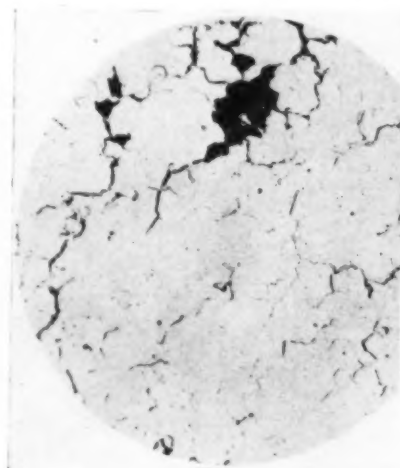


Fig. 9.

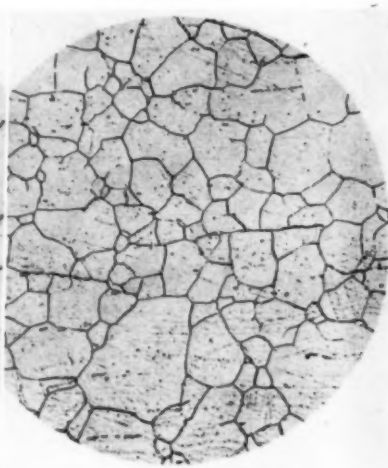


Fig. 10.

Fig. 9.—Intercrystalline crack near a weld. $\times 100$ Fig. 10.—An etched section showing carbide precipitation at the grain boundaries. $\times 100$

gas turbine manufacture where strength at high temperatures is a primary consideration.

It is hardly necessary to say that care is essential in choosing the correct composition of welding rod when very corrosive conditions are involved or high temperatures are encountered, and scale resistance and strength may be equally important.

The most disastrous failures followed the welding of steels of this type before intergranular corrosion was known or suspected, and it is significant that the term "weld decay" is still in common use. The cause of this trouble is still thought to be due to carbide precipitation at the grain boundaries and the evidence for this belief is shown pictorially in Figs. 9, 10 and 11. Fig. 9 shows an intercrystalline crack near a weld; Fig. 10, an etched section showing the carbide precipitated at the grain boundaries; and Fig. 11, a series of weld decay bend test pieces.



Fig. 11.—Showing a number of "weld decay" bend tests.

The susceptibility of a steel to weld decay is demonstrated by reheating a previously softened piece to 650° C. for half an hour. The cooled piece is then boiled in a solution of sulphuric acid and copper sulphate. If after 72 hours boiling the piece is free from weld decay, that is attack at the grain boundaries, it will emit a metallic ring when dropped on a hard wooden bench and will be sound when bent at right angles. If it has suffered attack at the grain boundaries it will have lost its metallic ring and the bent piece will be cracked on the surface. Such a test is part of most of the standard specifications for austenitic stainless steels for welding.

Weld decay freedom is usually ensured by the addition of titanium and/or niobium (columbium) which readily form carbides and prevent the formation of chromium carbide, which is the carbide that migrates to the grain boundaries to give the weld decay condition. Steel makers usually use titanium because it is cheaper, but welders usually use niobium-containing rods because, whereas 80% of the titanium contained in a core wire

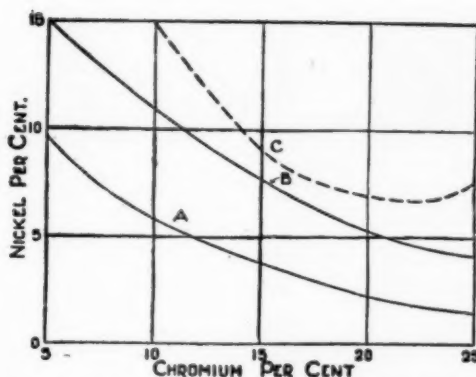


Fig. 12.—Effect of nickel in high chromium steels.

is lost into the slag during welding, only about 20% of the niobium is similarly lost under the same conditions

Austenitic stainless steels in the early days of their use were regarded as stable and free from vice, and being soft and non-magnetic were readily fabricated despite difficulties due to high rates of work hardening. The essential elements in this class of steel as indicated earlier are chromium and nickel, and broadly a relationship exists between the amounts of these two elements which will produce an austenitic steel. The effect of the nickel content on the production of austenite in high chromium steels is shown in Fig. 12 in which it will be seen that the amount of nickel required to produce austenite varies according to the amount of chromium present. Curve A indicates the nickel content necessary to give austenite after rapid cooling from high temperatures, while a completely austenitic steel is obtained when the nickel content reaches that indicated by Curve B. Still more stable austenite—resistant to drastic annealing—requires nickel contents according to Curve C. The several zones of the diagram are not, of course, sharp and precise, but merge through transition zones in which the austenite may be incomplete or unstable. This condition is frequently obtained when the chromium-nickel balance is disturbed and a second constituent or phase is introduced by the various additions made to this type of steel, and there is some evidence that it may also be somewhat disturbed by the effects of the steel-making conditions. Weld decay demonstrated one form of instability and the remedial

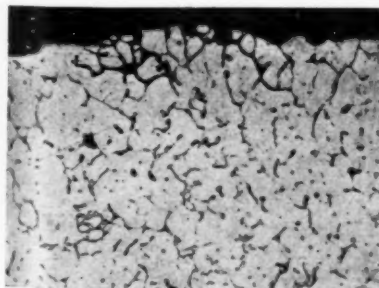


Fig. 13.

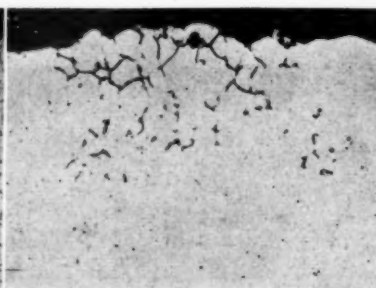


Fig. 14.

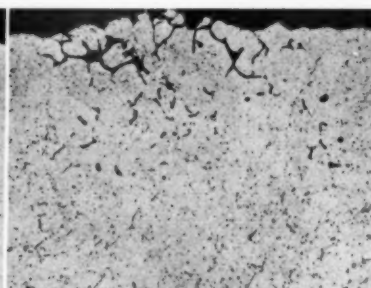


Fig. 15.

Fig. 13.—Showing cast structure of 18/8 steel containing niobium. $\times 110$ Fig. 14.—Same sample boiled in a weld decay test solution showing that the second constituent formed by the addition of niobium is less resistant to corrosion. $\times 110$ Fig. 15.—Similar section as Fig. 13 but etched to reveal carbides. $\times 110$

addition of titanium and silicon and some other metals showed further evidence that the balance of chromium and nickel needed little to disturb it. For example, niobium added to "18/8" and made into castings has the micro structure shown in Fig. 13 and the second constituent occurring in the primary structure is less resistant to corrosion than the matrix, as is shown in Fig. 14, which is the same piece boiled in the weld decay test solution mentioned above. Fig. 15 shows the structure etched to reveal carbides. It is clear that the corrosion in this case, unlike that of the weld decay condition, is not associated with the free carbide.

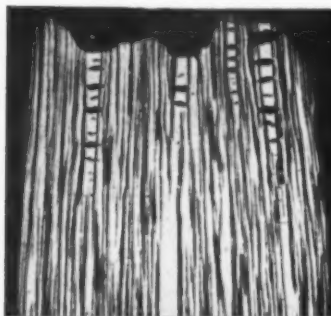


Fig. 16.

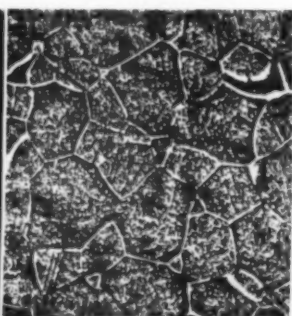


Fig. 18.

Fig. 16.—Section through a tensile test piece from a large diameter bar showing duplex structures. $\times 4$ Fig. 18.—Showing the effect of high-temperature treatment on the removal of the directional structure of the test piece shown in Fig. 16. $\times 4$



Fig. 17.—A hot-cut bloom end of a duplex austenitic steel.

Apart from the difference in resistance to corrosion exhibited by the two constituents in the previous illustrations, it is frequently found that the constituents of a duplex structure differ in their physical properties either at elevated temperatures or at normal temperatures, or at both. Ordinary non-stainless steels are not duplex in quite the same sense as the semi-austenitic materials but, owing to the coring which is inseparable from the solidification of steel, dissimilarities can be found in the primary or macro structure, and that these different parts of the structure have different properties is shown in Fig. 16, which is a section through a tensile test piece taken from a large diameter bar. The lighter etching parts are more impure than the darker parts and it is clear from the illustration that their capacity for cold deformation is considerably less than that of the purer parts in that local rupture has occurred. This dissimilarity in properties due to duplex structures also shows itself in hot working and the duplex austenitic steels are prone to tear on hot deformation. A characteristic hot cut bloom end is shown in

Fig. 17. The only means by which the differences constituting a duplex structure can be reduced is by high temperature heat treatment, generally for an extended time, whereby diffusion occurs and even if complete uniformity is not achieved the directional form of the structure can be altered and this change of form appears to have a beneficial effect on certain properties, e.g., resistance to creep. Fig. 18 illustrates the effect of high temperature treatment on the removal of the directional structure of the tensile test piece shown in Fig. 16.

One of the important features of these duplex austenitic steels is that they tend to harden and lose toughness when reheated at moderate temperatures of the order of approximately 650° to 900° C., the effective temperature generally decreasing with increasing time. These changes occur approximately in proportion to the amount of the ferritic phase present, but as nickel is the main austenitising element in these alloys more nickel will correct the action of the ferrite forming elements in producing the unstable condition. Molybdenum, commonly added to give enhanced corrosion resistance in amounts of approximately 2 or 4%, is an example of a ferrite forming addition, and the effect of increasing nickel in producing a stable austenite in a series of steels containing 18% chromium, 2% molybdenum and 1% niobium is shown in Fig. 19. With the lowest nickel content (6%) the impact in the softened condition is high but shows a pronounced fall on reheating and the toughness is not restored until the initial softening temperature is again reached. As the nickel content is increased, that is as the duplexity is reduced, the fall in impact on reheating becomes less and, at approximately 14% nickel, the fall in impact is almost completely removed, suggesting that, in the presence of 2% molybdenum and 1% niobium, 13 to 14% nickel is required to provide a stable austenite with 18% chromium. The effect of various additions of molybdenum, columbium and titanium to a 14% nickel chromium-nickel alloy is shown in Fig. 20. Generally, these additions reduce the toughness of the material and, whilst the values shown are experimentally determined ones, they are not necessarily quantitatively correct for all cases but the relative effects of the various additions will generally obtain. It will be noted that, although the inherent toughness of the material varies, 14% of nickel appears sufficient in all the examples shown to prevent any appreciable embrittlement on reheating.

Resistance to attack by sulphuric acid provides a good index of general corrosion resistance and it is of interest that the resistance to sulphuric acid in these alloys appears to be greatest with a material containing approximately 14% of nickel. As between the alloys containing 2 and 4% of molybdenum, the general resistance to corrosion of the 4% material is not significantly superior to that of the lower alloy content, although in certain specific cases the 4% molybdenum material is to be preferred.

Striking differences in properties, magnetic and mechanical and to some extent corrosion resistance, are produced by heat treatment of these duplex austenitic steels which are not far removed in analysis from the standard austenitic types. As an example, Table IV

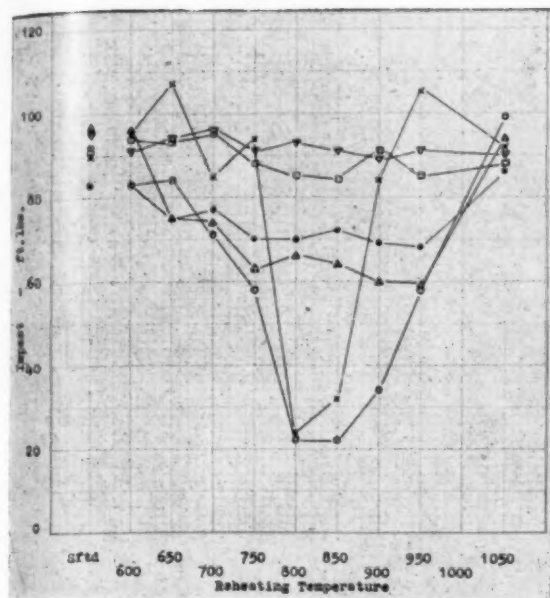


Fig. 19.—The effect of increasing nickel to an 18% chromium, 2% molybdenum and 1% niobium steel.

shows the effect of various heat treatments on a duplex steel.

It will be noted that the loss of impact, on reheating such a material—to which reference was made earlier—is accompanied by a considerable increase in hardness

TABLE IV.

C	Si	Mn	Cr	Ni	Ti
0.07	1.91	1.03	23.0	9.7	0.56
Treatment					
AC.925° C.	..	56	..	15.15.17	..
AC.925° C.—1 hr.—730° C.	..	68/70	..	3. 2. 8	..
AC.925° C.—48 hrs.—730° C.	..	70/74	..	8. 5. 8	..
AC.1050° C.	..	51	..	38.33.38	..
AC.1050° C.—1 hr.—730° C.	..	70	..	2. 2. 2	..
AC.1050° C.—48 hrs.—730° C.	..	71	..	2. 2. 2	..

and the assumption of a non-magnetic state. The structure of this steel in the softened, i.e., the most tough, condition is shown in Fig. 21 in which the proportions of ferrite and austenite can be seen. It is only the ferrite phase which undergoes a change on reheating but the effect on the mass is very striking.

Some use is being made of the hardening property of this type of steel and recently steels have been made in which the composition is so adjusted that the structure shows a preponderance of the ferrite phase. On reheating, these materials are capable of assuming quite high hardnesses but, as might be expected from the last example, the material becomes quite brittle. The effect of reheating on steel of this type is shown in Table V.

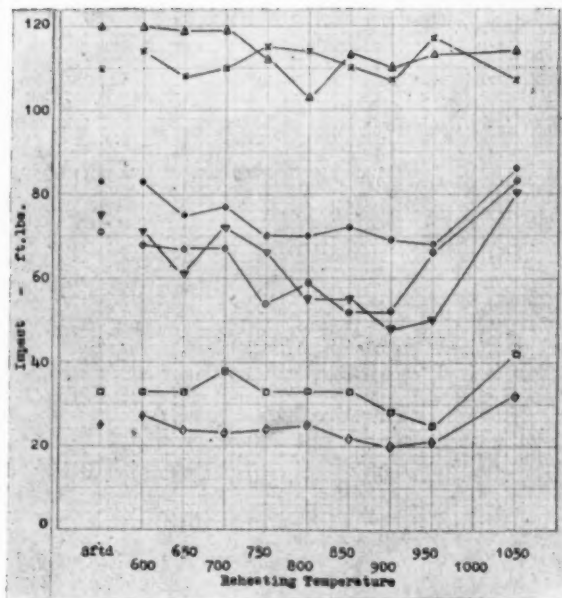


Fig. 20.—The effect of various additions of molybdenum, niobium and titanium to a 14% nickel chromium-nickel alloy.

It has been remarked earlier that in the complex alloy types the properties are very sensitive to slight composition changes. The data shown in Fig. 22 provide a good example of this. The steels are all of the type just described but the response to uniform heat treatment

TABLE V.

Cast	C	Si	Mn	Cr	Ni	Mo
HF.1719	0.08	0.33	0.49	26.7	5.5	1.36
Treatment						
As rolled—1½ in. dia.	..	Y.P.	M.S.	EL.%	R.A.%	Impact
Annealed—single anneal	..	45.2	50.8	24.5	48.5	12.13.11
WQ.925° C.	..	36.4	46.0	27.5	54.6	67.64.63
Proof Stress						
Annealed—double anneal	..	1%	2%	5%	M.S.	EL.%
48 hrs.—730/740° C., FC.	..	32.4	34.4	37.0	47.8	28.0
WQ. 925° C.	..	32.4	34.4	37.0	47.8	28.0
Precipitation hardened—	..	Very brittle—526 to 533 V.P.N.	..	..	..	..
48 hrs.—730/740° C., FC.	..	Y.P.	M.S.	EL.%	R.A.%	Impact
AC. 1200° C.	..	39.6	48.4	27.5	49.7	22.21.21

is markedly variable. Although the shorter times of reheating show that the development of the hardness is fairly gradual, the fall in impact is much more rapid and, in fact, after the shortest reheating time (¾ hour) the loss of impact is as complete as after the longest time (48 hours). Despite the disability of marked brittleness, these steels do find useful application in certain machine parts not subject to shock, i.e., pump parts where advantage is taken of the high hardness to prevent

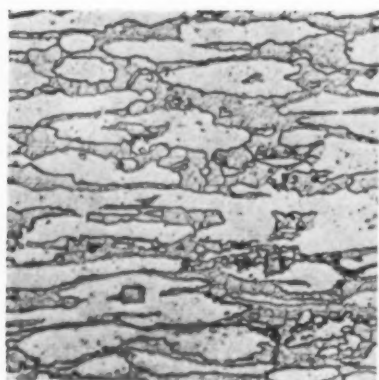


Fig. 21.

Fig. 21.—Structure of chromium-nickel (23/9.7) with 0.56% titanium in the softened condition. $\times 500$

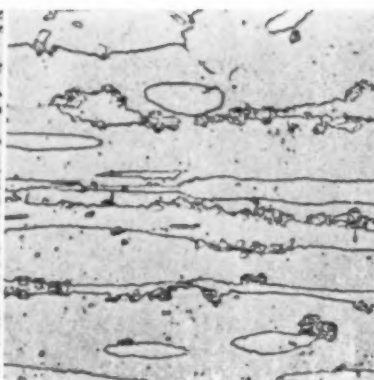


Fig. 23.

Fig. 23.—Structure of a chromium-nickel-molybdenum (26.7/5.5/1.36) alloy in the softened condition. $\times 500$



Fig. 24.

Fig. 24.—Structure of same material as Fig. 23 after reheating to break down the ferrite to form the hard brittle non-magnetic sigma phase. $\times 500$

seizure which is prone to happen with materials of similar hardness. One practical point for the engineer to note is that the change from the soft tough condition to the hard brittle one is accompanied by a reduction in size, and due allowance should be made before heat treatment. The microstructure of one of these steels in

the softened condition is shown in Fig. 23 and the excess of the ferritic phase will be noted. The breakdown of the ferrite with the formation of the hard brittle non-magnetic sigma phase resulting from reheating is shown in Fig. 24.

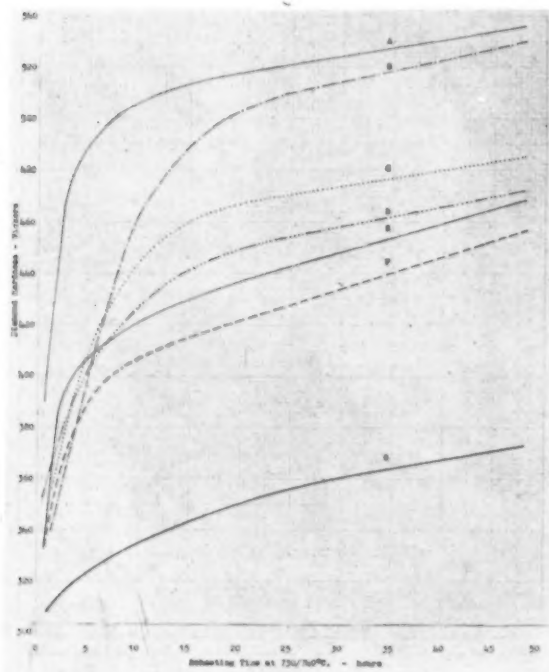
Irrespective of the type of stainless steel, the effects commented upon show that the material may be adversely affected in some way by heating to comparatively low temperatures, such as inevitably occurs at some part of the heat gradient set up in welding. As so often happens, the steps taken to cure one ill frequently give rise to another one, especially in the more complex type where the characteristics are inherently so sensitive to small changes in analysis.

Perhaps one good reason for bringing such results before those especially interested in welding is the knowledge that dissimilar metals are often joined, or that a welding rod of a different metal is used to join similar parents. Examples are the laying on of a hard facing metal, the use of austenitic 25/20 rods for joining high chromium steel, with a resulting composition about the joint which is not determinable by analysis but must bear a distinct relationship to some of the compositions whose behaviour has been described and which may be hard, brittle, and occupy a less unit volume than either parent or welding rod.

Large amounts of these materials are, of course, successfully used in spite of their disabilities, and it is the constant aim of producers of these steels to improve the types, both as regards their manufacture and usage and the scope of their successful application in industry.

The Midland Area Offices of the Rockwell Machine Tool Co., Ltd., are now situated at 132, Steelhouse Lane, Birmingham, 4, Telephone Central 3692-3.

The Distillers Co., Ltd., announce that they have authorised expenditure of about £2,000,000 with the view to expanding the output at the works at Salt End, Hull, belonging to their subsidiary, British Industrial Solvents, Ltd. The products involved cover solvents, plasticisers and acetic acid and anhydride. This expansion is necessitated by the growth of consumption of these products in the plastics, rayon, fine chemical and dyestuffs industries.



Steel	C	Si	Mn	Cr	Ni	Mo
A	0.06	0.43	1.52	27.2	4.51	1.41
B	0.05	0.47	0.66	26.8	5.19	—
C	0.07	1.64	0.62	27.1	5.13	—
D	0.08	0.33	0.49	26.8	5.50	1.36
E	0.09	0.55	0.57	27.0	5.01	1.36
F	0.06	0.36	0.65	27.0	4.54	1.39
G	0.06	0.57	0.44	25.9	4.01	1.39

Fig. 22.—Showing how sensitive the complex alloy types are to slight composition changes.

Testing Acid-Resisting Steels for their Resistance to Intercrystalline Corrosion

Dr. mont. Ing. Siegfried Plankensteiner,
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A report is given, based on experiments and tests, on the determination of the resistance to intercrystalline corrosion of austenitic chromium-nickel and chromium-nickel-molybdenum steels. In addition to the copper sulphate solution in sulphuric acid, generally used as the testing liquid, a new testing liquid, developed by the author, is used by means of which it is claimed that a quicker and more accurate test is made possible.

THE testing of acid-resisting steels with the object of determining their relative resistance to intercrystalline corrosion is not only of interest to manufacturers of alloy and special steels, but also to metallurgists, chemists, chemical engineers and manufacturers of chemical plant and apparatus. In order, therefore, that this discussion may be more complete it is considered desirable to deal briefly with the nature of intercrystalline corrosion, its cause and the possibilities of its prevention.

Intercrystalline Corrosion

Austenitic chromium-nickel, chromium-nickel-molybdenum and chromium-manganese steels, as well as ferritic and martensitic chromium steels, after appropriate heat-treatment, are able to resist various corrosive agents; but subsequent heat-treatment, incurred in processing these materials, may and does cause a substantial reduction in their resistance to corrosion. This occurs when the structure of the steel, particularly at the grain boundaries, has been altered by such treatment. In such cases the corrosive agents cause comparatively little or no surface damage, but penetrate into the material and attack the grain boundaries, causing the grains to lose their cohesion, which may result in the sudden collapse of the material. This phenomenon is generally known as intercrystalline or intergranular corrosion.

The alteration in the structure of these materials is due to the separation of carbides rich in chromium along the grain boundaries of the austenite as a result of the influence of temperature: the range of this temperature in austenitic chromium-nickel and chromium-nickel-molybdenum steels is between 500° and 900° C. In the separation which occurs the immediate surroundings of the grains are deprived of part of the chromium and the resistance to corrosion of the grain boundaries is reduced from that of the initial structure. In addition such separations can cause mechanical stresses as well as the formation of local cells in the grain boundaries, which cause an additional reduction in the resistance to corrosion. Recent researches also show that the proportion of oxygen to the carbon contained in the steel has an important influence.

The modifications of texture of these materials are more frequently encountered when their fabrication involves welding. In this operation the material is subjected to a heating-treatment, which, according to the distance from the weld, comprises the range from melting to room temperature, and, of course, includes the critical

range for the alloy steel in question. The texture of the affected parts may be restored by appropriate heat-treatment, but, apart from the additional cost involved in many cases large furnace plant would be necessary to deal with chemical plant structures and there would be difficulties arising from the high temperatures necessary causing deformations. Indeed, for some time fabricating large sized chemical plant by welding acid-resisting steels was considered unsatisfactory.

That problem has been largely overcome by more recent metallurgical developments. Alloy and special steel manufacturers carried out investigations and experiments showed that the difficulty was not so pronounced when the carbon contents was low, substantially reducing the amount of chromium taken up in the form of carbides. Further improvements were effected by the use of such alloying elements as titanium or niobium, which have a higher affinity for carbon than chromium and thus form their respective carbides, and in this way they tend to protect the initial structure of the austenitic steel. Methods of heat-treatment have also been improved to reduce changes in the structure.

Success in the solution of the problem depends, in some measure, on the technique and degree of control employed in the manufacture of the steel, and it is customary to make a test on each charge in order to determine its resistance to intercrystalline corrosion.

Testing Methods

To achieve quick results corrosive chemical agents should be used for this test against which the homogeneous crystals of the steel to be examined exhibit a very high resistance. In this way the surface corrosion is relatively small, whereas if the resistance at the grain boundaries is low, due either to faulty structure, mechanical stresses or local cells, corrosion will proceed rapidly around the crystals. To make this test as quickly as possible Hatfield* suggested an acid copper sulphate solution with 111 gms. crystallised CuSO_4 and 98 gms. concentrated H_2SO_4 (Sp.gr. 1.84) per litre, dissolved in water, as an appropriate testing liquid. With very slight modifications by the steelmaker, as well as by the consumer, this method has become the general practice, although the test samples require to be boiled in the liquid for at least 3 days, a not inconsiderable time in these days, when speed coupled with accuracy is important.

To shorten the testing time and because of temporary difficulties in obtaining the CuSO_4 , the writer has carried

* W. H. Hatfield, *Jour. T.S. Inst.*, 127 (1933), 381,407.

out some investigations from the results of which it was found that a pure sulphuric acid solution with 0.5% by weight of H_2SO_4 proved to be more expedient than the above solution in general use. As a result of the work the writer considered the following procedure gave satisfactory results.

Procedure of Test with Sulphuric Acid Solution

Specimens of the material, to be examined for their susceptibility to intercrystalline corrosion, which are given an appropriate heat-treatment, must be exposed to a suitable testing liquid long enough to permit attack. The investigation can then be verified by watching the permeating effect of the intercrystalline attack by means of the microscope or by determining the increase of electrical resistance to induction on the flat-shaped cross section of the specimens, since the electrical resistance rises as intercrystalline corrosion proceeds. Another test method less accurate than the foregoing, but much simpler and quicker, and which proved quite satisfactory for regular tests consists in submitting small plate specimens to a sound and bend test after boiling the plates in the testing liquid. Following intercrystalline attack the samples lose their shrill metallic sound; when the attack is particularly well advanced the sample may lose its metallic ring completely, resembling that of lead. With practice it is possible to estimate the extent of intercrystalline corrosion in the sample. A further test frequently used is the bend test. In this method plate samples, which have been submitted to the attack, are given standard bend tests when interruptions in the grain boundaries caused by corrosion will result in tears, the size, number and distribution of which indicate the extent of the intercrystalline corrosion.

Experimental Work

Plate tests were carried out on austenitic chromium-nickel and chromium-nickel-molybdenum steels, details of which are described in the following notes:—

Preparation of the Test Specimens.—A small sample sheet could be rolled from each charge, but forging a plate as thin as possible from the final melting sample is quite satisfactory. For these experiments the sample was forged flat to about 2 mm. thick. Great care must be taken that the prescribed ranges of forging temperatures—1,150°–900°C.—are adhered to, because grain size has an influence on the resistance to intercrystalline corrosion. With increasing grain size the extent of the grain boundaries becomes smaller and the separation of carbides, based on the total of the grain boundaries within a certain volume, is intensified, and the susceptibility to attack becomes greater. From this forged plate three specimens are cut, each about 50 mm. long and 35 mm. wide after grinding the forged edges straight.

One of these specimens is used for the sound and bend test, the other two for the welding test (Fig. 1). It will be noted that two of the samples have holes drilled through them to facilitate hanging in the testing liquid and two plates carry a reference number. Each plate is neatly ground to provide a surface similar to a rolled and pickled sheet.

Heat-treatment of the Samples.—To obtain a homogeneous austenitic structure all specimens are heated in a furnace regulated to a temperature of 1,050°C., held at this temperature for 1 min., and then quenched in water. The duration of holding temperature is counted from the moment the samples reach the flame colour of

the furnace, which for 2 mm. thick plates is about 3 min. Experience has shown that a holding time of 1 min. has no perceptible coarsening effect on the grain.

The sample intended for the sound and bend test is drawn for 30 min. at 650°C. This temperature was determined as a result of a series of tests covering temperature and the duration of time a particular temperature is maintained. As previously mentioned, drawing temperatures between 500° and 900°C. are dangerous, but low temperatures and short drawing times cause only trifling separation of the carbides and therefore little reduction of the resistance to intercrystalline corrosion. On the other hand higher temperatures and long drawing times cause a stronger conglomeration of carbides and a certain equalisation of the contents of chromium by diffusion in the grain boundaries impoverished through the separation of carbides, and a slight reduction of the intercrystalline corrosion resistance results. For a drawing temperature favourable for the lucidity of the test and likely to produce conditions most unfavourable to the steel, a temperature of 650°C. and a drawing time of 30 min. was found to be best.

After heat-treatment the sample for sound and bend tests is ground to a fine finish but in a direction at right angles to the bend test. In this way fine cracks which may develop are more clearly shown.

The welding test is a more practical method of determining the fitness of a steel to resist intercrystalline corrosion, although the effect is not so severe as when a drawing treatment is given as for the sound and bend tests. In welding the steel is heated for a comparatively short time to the critical range, and the effect is not so unfavourable to the steel. Practical experience has shown, however, that the influence of such a short time at the critical temperature is quite sufficient to cause trouble through intercrystalline corrosion as indicated by Rollason* who showed the connection between drawing temperatures and drawing times and their influence on intercrystalline corrosion. (See Fig. 2).

The samples are welded together in the quenched state and the pieces are welded together by means of an oxyacetylene flame because it is considered that this method has a better drawing effect than electric welding and will, therefore, produce in the steel slightly less resistance to attack. After welding, the temper colours near the weld are removed by pickling in solution consisting of 50 parts by volume of water, 45 parts of concentrated muriatic acid and five parts of concentrated nitric acid. Experience has shown the most satisfactory pickling time to be about 7 min.

Selection of Appropriate Testing Liquid.—As mentioned previously, the acid-copper-sulphate solution recommended by Hatfield is generally used. In considering this solution there arose the question whether the 111 gms. $CuSO_4 + 98$ gms. concentrated H_2SO_4 should be dissolved in 1 litre of water as Monypenny suggests in his book, "Stainless Iron and Steel" (1931), or whether the same quantities of $CuSO_4 + H_2SO_4$ should be completed with distilled water to make 1 litre as the building materials specification of the British Air Ministry (D.T.D. 176A of November, 1932) prescribes. In the first case the solution contains 85.5 gms. $H_2SO_4 + 65.2$ gms. $CuSO_4$ (free of water) in the litre, while in the second case the calculation shows 93.7 gms. $H_2SO_4 + 71.0$ gms. $CuSO_4$ (free of water) in the litre.

* E. C. Rollason, *Jour. I.S. Inst.*, 127, 1933, 391–414. (See also *Stahl und Eisen*, 1933, page 1006.)

The question naturally arose whether such differences in concentration have an essential difference on the result of the experiment. If consideration is given solely to sulphuric acid solutions, without the addition of copper sulphate, the conclusion would be reached that the second solution will have a much stronger effect. Comparative tests were made to determine the relative effect of these solutions and there appeared to be no

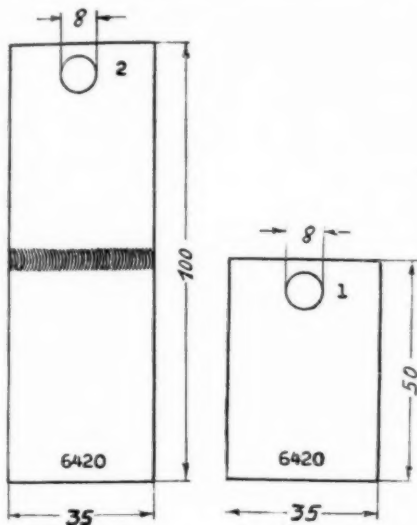


Fig. 1.—Specimens for welding test (left) and for sound and bend tests (right).

difference in the experimental results. This seems to be confirmed by other workers; for example, Houdremont in his "Handbuch der Sonderstahlkunde (page 503) gives 15% H_2SO_4 + 10% $CuSO_4$ for the so-called grain decomposition solution.

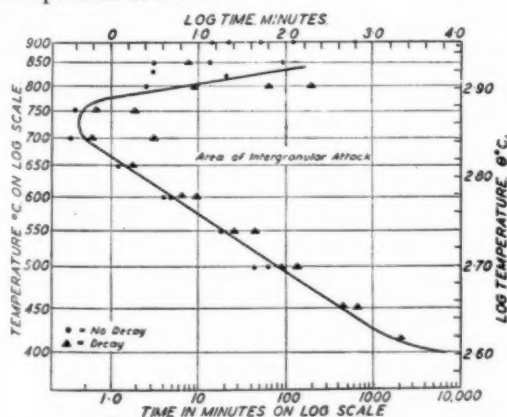


Fig. 2.—Influence of the drawing temperature and its duration on the susceptibility to intercrystalline corrosion of a steel composed of 0.19C, 0.30 Si, 0.73 Mn, 15.2 Cr and 10.9% Ni. After Rollason.

After careful investigation of the literature on the subject, it would seem that only copper sulphate solutions in sulphuric acid have been used to verify the resistance of a steel to intercrystalline corrosion. Obviously, workers generally have been convinced that the

testing liquid suggested by Hatfield is the strongest to set up intercrystalline corrosion, and it has been assumed that steels capable of withstanding this attack could be used without fear in those cases where intercrystalline attack was to be expected. In our work, however, it has been proved that a steel capable of resisting attack by this test solution is not necessarily immune from intercrystalline corrosion.

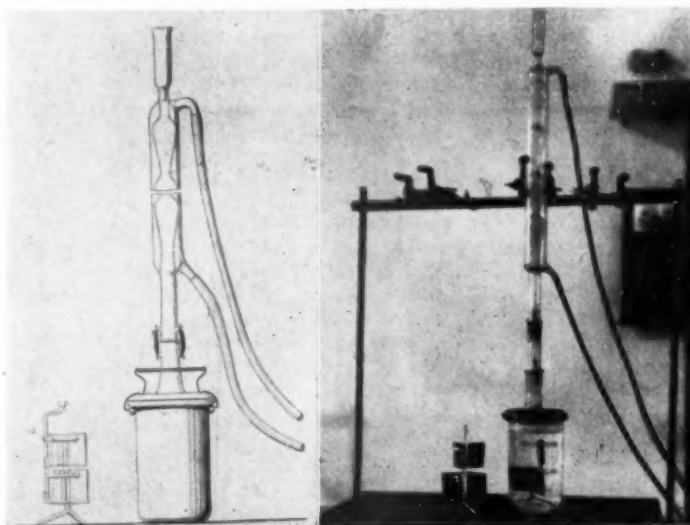


Fig. 3.—Apparatus for the testing specimens to determine their resistance to intercrystalline corrosion.

The primary object of these experiments was to effect a reduction of the testing time. At the time, however, it was difficult to procure the copper sulphate, which made it necessary to experiment with a view to omitting it entirely from the testing liquid. Since investigations in the technical press for alternative solutions proved abortive, it was necessary to try several possible solutions.

The main point was to choose a testing liquid against which the steel in its heat-treated condition offered good resistance and yet would readily attack the grain boundaries. At first a series of tests was carried out with different nitric acid concentrations, but only a few positive results were obtained with a solution containing 2.5% nitric acid. Thus, this solution proved to be much less serviceable than the copper sulphate solution now in general use. It seemed desirable to make use of the strongly passivating influence of the nitric acid and yet be able to aggravate the attack in the grain boundaries impoverished in chromium. Further tests were, therefore, made with several solutions; the first containing 10% HNO_3 + 1% H_2SO_4 , and the second 10% HNO_3 + 10% H_2SO_4 (percentage by weight). These solutions also proved to be inferior to that generally used.

Tests with Sulphuric Acid Solution

Another series of tests showed that a pure sulphuric acid solution of 1% clearly indicated intercrystalline corrosion, but heavy destruction of the surface took place, which made the results less clear. The results, however, indicated a possible field for exploration, and it was ultimately found that, by diluting the sulphuric

acid solution so that it contained 0.5% sulphuric acid, an excellent testing liquid was obtained. By using this solution the testing time can be reduced to 24 hours, which is about one-third of the time necessary with the copper sulphate and sulphuric acid solution.

Despite the shorter duration of the test, it is possible to distinguish to a better degree of accuracy the resistance of samples to intercrystalline corrosion. In some cases where tests have been made by the usual method and found to be intercrystalline corrosion-resistant, test pieces from the same melt have been subsequently tested by the new method and the results have shown a slight but distinct attack of intercrystalline corrosion.

The results of tests made it evident that a uniform test permits only relative evaluation of the melts. If a melt, as a result of testing in a copper sulphate solution in sulphuric acid, proves to be perfectly resistant, this is no guarantee of resistance to intercrystalline corrosion in dilute pure sulphuric acid solutions. On the other hand, it is reasonable to conclude that a melt which can stand a test in dilute sulphuric acid will be safe against attack if treated in a copper sulphate solution in sulphuric acid. However, each method has its limitations: in some cases the dilute sulphuric acid solution might be too severe a test, whereas in other cases the copper sulphate solution in sulphuric acid might be too weak a test.

Testing Equipment

The test is made in boiling liquid, and, in order that no alteration of the proportions of the concentration should occur, it is carried out in closed vessels with backflow coolers. The testing equipment which has proved very satisfactory is shown in Fig. 3. The vessel containing the testing liquid and the specimens to be tested is closed with a glass cover ground at the junction, since rubber or cork stoppers would be destroyed rapidly by the vapours. For better tightness between cover and the vessel, the contacting surfaces are slightly greased and the cover is tightened by clamps and springs. A little glass stand serves to hang up a large number of test specimens in one vessel, such as is shown in Fig. 3. It is important that the test specimens do not touch each other. This can be avoided by placing glass rings between each.

Critical Examination of Specimens After Boiling

The bend tests are made by bending specimens through an angle of 90°, but in some cases when deep cracks occur the bend will be considerably less. It is necessary to standardise this test somewhat to keep the bending radii equal to about three times the thickness of the test specimens. The evaluation in the case of cracks appearing is usually determined with the naked eye, if the resistance is insufficient. On the other hand, when the resistance to attack is appreciable, the examination is more satisfactorily carried out with the aid of a magnifying glass having a magnification up to about 20.

In addition to making a distinction between resisting and non-resisting steels, according to size, number and distribution of the cracks, a further classification of the not absolutely resisting melts can also be made. In doing this, experience is necessary to allocate the position for welded parts where an absolute resistance to intercrystalline corrosion is not so vitally important as in the present test. For example, in products likely to get

rusty or to be attacked by weak organic acids contained in food, the danger of intercrystalline corrosion is either non-existent or of a very trifling character. An example is shown in Fig. 4, giving the results of tests on a melt consisting of 0.14 carbon, 0.39 silicon, 0.35 manganese, 17.81 chromium, 9.80 nickel and 2.02 molybdenum.

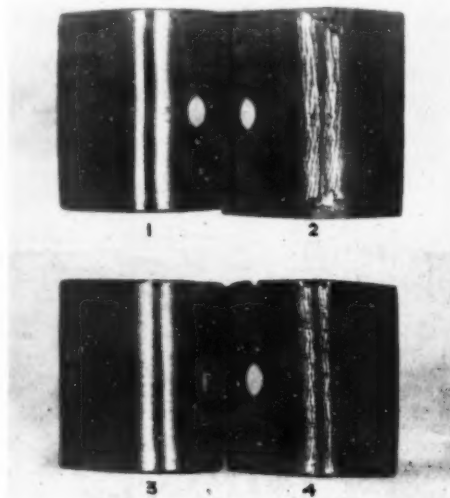


Fig. 4 (above).—Result of bend test after boiling in 0.5% sulphuric acid solution for 24 hours.

(Below).—Result of bend test on similar material after boiling in copper sulphate, sulphuric acid solution for 72 hours.

The testing specimens 1 and 3 were examined in comparison with each other in the quenched state, while the test specimens 2 and 4 were submitted to a critical drawing treatment at 650° C. for ½ hour previous to treatment in the testing liquid. The testing specimens 3 and 4 were boiled in copper sulphate solution in nitric acid for 72 hours; the test specimens 1 and 2 in 0.5% sulphuric acid solution for 24 hours. It will be seen from the illustration that the test carried out in the 0.5% sulphuric acid solution in 24 hours gives a similar result to that carried out in the copper sulphate solution in sulphuric acid for a period of 72 hours.

The welding test specimens are bent close to the weld, and again parallel to the same bend, until eventually cracks form which are judged according to their extent either with or without a magnifying glass.

Summary

After a short introductory discussion on the reasons for intercrystalline corrosion and on the measures taken for its prevention, practical tests are described on austenitic chrome-nickel and chrome-nickel-molybdenum steels, with a view to determining their resistance to intercrystalline corrosion. In connection with this, the writer reports on a new testing liquid by means of which a clearer and more accurate test can be made of acid resisting austenitic chrome-nickel and chrome-nickel-molybdenum steels than with the copper sulphate solution in sulphuric acid generally used.

From *Industrie und Technik*, 1947, 2, 16-20.

Automobile Exhaust Valve Materials and Lead Attack

By R. J. Brown, F.I.M., A.M.I.Mech.E.

Two forms of corrosion are discussed which are due to lead attack on automobile exhaust valve material. Various materials are considered and it is stated that the ideal valve material has yet to be discovered. The problem is claimed to be one of faulty combustion rather than of faulty metallurgical technique and is, therefore, a problem for the fuel technologist, although the closest co-operation between the designer, metallurgist and fuel technologist is vital if the demands for ever-increasing engine efficiency are to be met.

Introduction

THE problem of lead attack of valves has been at some time or another, a foremost problem with both makers and users of internal combustion engines operating on petrol. Prior to the introduction of leaded fuels considerable progress had been made since the early days, when valve failure after a very short life was the rule rather than the exception, culminating about 1930 in the widespread adoption of Silchrome No. 1 steel for exhaust valves; for some years a lower grade of Silchrome steel had been widely used with considerable success.

Silchrome No. 1, the composition of which is quoted later, is a heat-resisting steel, and gave excellent service with straight petrol, and also with benzol and alcohol mixtures, but with the introduction of leaded petrol it became apparent that a better material was desirable, although valve failures due to the use of this fuel were not excessive prior to the outbreak of the recent war, providing that the engines in which it was used were maintained in a good state of mechanical efficiency.

The reason for additions of tetraethyl lead to petrol is to bring about an increase in its octane rating, thus increasing the anti-knock value of the base fuel. The combustion of this tetraethyl lead in the engine causes the formation of harmful lead compounds, mainly lead-oxide, which results in the so-called "hot corrosion" of the valves: to overcome this, ethyl dibromide is also introduced with the tetraethyl lead. This additional compound results in the formation of lead bromide, which is volatile during the combustion of the fuel, and this volatile product escapes with the exhaust gases. For some inexplicable reason, although it may have been the increasing shortage of bromine with the increased use of leaded fuel, a small amount of ethylene dichloride was substituted for the dibromide and it is evident from the increased effect of the leaded Pool Spirit on valve life as compared with pre-war Ethyl petrol that further changes were made in the composition of Ethyl fluid, probably owing to the exigencies of war, the halogen carrier being increased in proportion to the tetraethyl lead, and consisting of about equal quantities of ethylene dibromide and ethylene dichloride.¹

Unfortunately, the added ethylene compounds do not entirely remove, with the exhaust gases, the lead compounds produced during combustion and they themselves also deposit decomposition and condensation products in the combustion space of the engine, which owing to their acidic nature lead to severe cold corrosion, particularly in engines which are allowed to stand for

long periods after use with leaded petrol. To counteract this cold corrosion an inhibiting mixture has been developed for introduction into engines which have to be stored for extended periods after running with leaded petrol.²

Of the two forms of corrosion which occur in service "hot corrosion" is the most serious as it may lead to rapid valve failure, particularly in the absence of adequate facilities for frequent servicing of the engine.

Valve Failure

The failure of valves, usually referred to as "burning," may occur during normal operation, or it may be the result of sticking of the valve in the valve guide due to cold corrosion or choking with deposited combustion products. For the purpose of this paper it is assumed that the valves are free in their guides until they seat so badly that loss of power indicates their failure.

The solid combustion products deposited on the valve heads when leaded fuel is used are considerably greater than when straight petrol is used, and they are also of different composition and character. In the absence of lead, deterioration of the valve seat due to build up with these products is negligible, whereas with leaded fuels a deposit quickly forms on the seat. Ultimate failure of exhaust valves takes the form of local, or in some cases general, burning of the seat and it is believed to be due to a variety of reasons such as bad seating caused by oxidation and consequent sinking of the valve seat,³ or to particles of the combustion products becoming detached from the combustion space and embedding themselves temporarily in the valve seat, thus destroying a satisfactory gas seal and also tending to distort the valve owing to the plasticity of the steel at its working temperature.

As a result of an examination of numerous valves removed from engines run with straight and leaded fuel, the writer is of the opinion that ultimate failure with the latter fuel is due to progressive building up of the valve seat with the solid combustion products to a point at which they form so thick a layer that they crack and flake away, thus destroying the requisite gas seal; the hot exhaust gases charged with lead compounds are thus able to blow-by at the point of failure, leading to severe local oxidation, scaling and erosion and to final destruction of the valve by "burning."

In the absence of lead, valve failures when Silchrome No. 1 is used are rare, and when they do occur it is generally due to bad seating resulting from insufficient

¹ "Leaded Fuels in Internal Combustion Engines," by P. O. Lemereque, A.E. 1943/14.

² "Some Problems of Modern High Duty Aero Engines and their Fuels," by F. R. Banks, *Journal of the Institution of Petroleum Technologists*, 23, No. 169, February, 1937, p. 957.

³ "Valve and Valve Seat Technique for Automobile and Aero Engines," by F. R. Banks, *Jour. I.A.C.*, 33, p.359.



Fig. 1.



Fig. 2.



Fig. 3.

Fig. 1.—Pitting of Silchrome No. 1 valve head when leaded petrol is used. Fig. 2.—Local valve seat failure. Fig. 3.—Failure by radial fissures.

attention after very extensive service. The formation of oxide on the valve seat due to slight sticking of the valve in its guide, or distortion resulting from dislodged oxide becoming entrapped on the valve seat will allow the hot oxidising exhaust gases to blow-by, and this naturally leads to rapid failure by burning. Poor seating of the valve due to any cause is noticeable by a general falling off in power of the engine, and valve failure will not occur if the valves are reseated by grinding in.

In addition to deposition of solid products of combustion on the valve head, leaded fuels also cause pitting of the steel by chemical attack, this being the effect covered by the term "hot corrosion." This effect, illustrated in Fig. 1, is only observed plainly when the valve head is cleaned.⁴

Two types of valve failures are regularly found in service, one taking the form of general deterioration of the seating surface, as shown in Fig. 2, and the other taking the form of radial fissures which are rapidly opened out, as shown in Fig. 3.

The first type of failure is believed to be due to hammering of the deposit formed into the valve seat, the compacted deposits subsequently breaking away, thus destroying the gas seal. The second type of failure is somewhat different in character; it is considered to be due to the formation of radial cracks in the deposit, the steel at the base of these cracks being thereby exposed to further attack by the exhaust gases; in this way they are opened out, finally forming "gutters" due to combined hot corrosion of the steel, and erosion resulting from the velocity of the exhaust gases; radial cracking of the matter deposited on the valve head is undoubtedly due to expansion and contraction of the valve during service.⁵

Examination of Silchrome exhaust valves used with straight and leaded fuel is interesting and indicates little difference in the actual mode of attack of the steel itself, although their useful life is reduced by the lead compounds, and the composition of the solid products is different. Sections prepared by cutting used valves through the centre line of the head are illustrated in Figs. 4 to 7. It will be observed that in Figs. 4 and 6

the structure of the deposit varies, but it is generally complex and of the type shown in Fig. 6; the different structures produced with leaded fuel may result from variation in the operating conditions, although the chemical composition of the deposits is similar. The deposit shown in Fig. 4 is relatively soft and flakes easily, whereas that shown in Fig. 6 is more compact; the former was located in a pit formed in the valve seat and the latter was representative of a semi-continuous deposit on the seat itself. Cracking of the deposit is also visible in Fig. 6, this being indicated by the arrows.

The steel underlying the deposit shows no serious decarburisation or oxide penetration of the surface, typical oxidation being shown in Fig. 7; even with this sample the penetration is very slight. The difference in surface attack of the steel comprising the valve seat, illustrated in Figs. 5 and 7 indicates that the operating conditions may affect the mode of failure of the valves.

It appears evident, therefore, that failure of valves in Silchrome No. 1 should not occur any more rapidly with leaded fuel than with plain fuel providing they seat satisfactorily at all times, and it is not unreasonable to assume that their rapid failure is attributable to either (a) increased build up of combustion products on the valve seats and head to a point at which the deposits readily crack or flake away, or (b) loose particles of cylinder head and piston deposits becoming embedded in the valve seat, thus allowing gas leaks.

With regard to the latter cause, it should be remembered that at the working temperature of the valve, Silchrome No. 1 is comparatively plastic, facilitating damage to the seat by loose particles.

The range of approximate chemical analysis of four typical valve head deposits produced with straight and leaded fuel and examined by the author are given in Table I, and it will be seen that whereas the deposit is largely carbonaceous matter when straight fuel is used, it is composed mainly of lead carbonates and oxides

TABLE I.—CHEMICAL ANALYSIS OF VALVE-HEAD DEPOSITS

	Straight Petrol		Leaded Petrol	
	1	2	1	2
	pc	pc	pc	pc
Insoluble matter	0.5	12.01	1.5	2.01
Iron Oxide (Fe_2O_3)	5.5	18.0	2.5	16.0
Carbonaceous matter	93.0	65.0	4.0	1.0
Lead Chloride	—	—	1.7	2.7
Lead Carbonate and Lead Oxide	—	—	Rem.	Rem.

⁴ "Some Problems of Modern High Duty Aero Engines and their Fuels," by F. R. Banks, *Journal of the Institution of Petroleum Technologists*, 23, No. 180, February, 1927, p. 957.

⁵ "Internal Combustion Engine Exhaust Valve Failures," by C. C. Hodgson, *Journal of the Iron and Steel Institute*, 1933, No. 1.

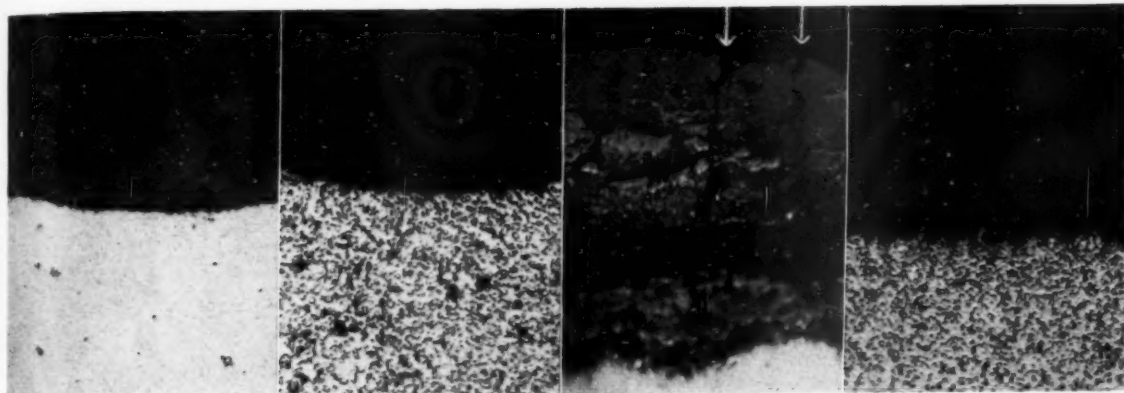


Fig. 4.— $\times 500$. (unetched) Fig. 5.— $\times 500$. (unetched) Fig. 6.— $\times 500$. (etched) Fig. 7.— $\times 500$. (etched)
Sections through seat of valve used with leaded fuel.

with leaded fuel. Assuming that the quantity of carbon deposited is similar with both types of fuel for a given time of engine operation, the thickness of the total deposit will be much greater when leaded fuel is used, this being confirmed in practice.

Valve Materials at Present in Use.

In addition to Silchrome, austenitic steel of the DTD.49B type has been used to a considerable extent for many commercial vehicles, cars of the sports type, and air-cooled motor cycles in this country, and it is extensively used for aircraft engines.

Means whereby the life of valves can be extended, fall into three groups as follows:—

(a) Deposition on the seat of a material highly resistant to oxidation and lead attack at the working temperature, and probably over the whole of that part of the valve which is exposed to the products of combustion.

(b) Use of materials for the valve itself which are more resistant to lead attack than those generally used.

(c) Cooling of the valve by filling with sodium or coring with a material having better heat conductivity than the valve material itself.

A combination of all three methods of improving valve life is resorted to in the aircraft industry, which uses leaded fuel with an octane rating of 100+, as compared with a much lower value for vehicle fuels.

The main object of this article is a consideration of the materials used for exhaust valves, these being of two classes:—

1. Ferritic. 2. Austenitic.

The former have in the past been represented by the Silchrome steels of the type covered by BS.970 En.52, and the latter by DTD.49B, their chemical composition being given in Table II.

Both steels are in the heat-treated condition; Silchrome valves are oil-quenched from a temperature

varying from 950 to 1,050° C. according to the characteristics of the particular cast of steel, followed by tempering at a temperature between 650 and 850° C., the resulting structure being of highly dispersed spheroidal particles of carbide in a troosto-martensitic matrix, as shown in Fig. 8.

The austenitic steel is heat-treated to produce a fully austenitic structure in which highly dispersed carbide particles occur as shown in Fig. 9; the treatment consists of heating to 1,050° C. and cooling at a suitable rate according to the size of the valve head.

The mechanical properties of these steels at room temperature are given in Table III, and at elevated temperatures in Table IV. From the latter it will be seen that the hot strength of the Austenitic steel is much higher than that of the Silchrome, so that it is better able to resist distortion should loose particles of deposit become entrapped on the valve seat.

TABLE III.—SPECIFIED MECHANICAL PROPERTIES OF VALVE STEELS AT NORMAL TEMPERATURES

	Silchrome No. 1 En. 52	Austenitic DTD. 49B
Ultimate Strength—tons/ sq. in.	55–65	(45–60)
Elongation—%	25 min.	(25 min.)
Reduction of Area—%	50 min.	(38 min.)
Izod Value—ft./lb.	(10 approx.)	15 min.
Brinell Hardness	255/293	302 max.

(The values in brackets are those which may be expected in practice and for which no specification is quoted).

TABLE IV.—TENSILE STRENGTH OF VALVE STEELS AT ELEVATED TEMPERATURES (°)

	Silchrome No. 1 Fox. 1037	Austenitic Fox. 1049
Ultimate Strength at 20° C. tons/sq. in.	59.2	54.1
700° C.	6.7	23.6
800° C.	3.2	12.2

One disadvantage of austenitic steels for valves is their high co-efficient of expansion, this being 18×10^{-6} compared with 13×10^{-6} for Silchrome. This fact necessitates increased tappet and guide clearance if the valve is to operate satisfactorily at working temperatures. A further disadvantage is the danger of scuffing of the valve stem owing to the relatively soft nature of the steel.

New Materials for Valves

In recent years, three steels having considerable promise have been developed in the U.S.A.; whereas

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TABLE II.—CHEMICAL COMPOSITION OF BRITISH VALVE STEELS

	Silchrome No. 1 En. 52	Austenitic DTD. 49B
Carbon	0.40/0.50	0.35/0.50
Manganese	0.30/0.60	1.50 max.
Silicon	3.00/3.75	1.00/2.50
Nickel	0.50 max.	10.00 min.
Chromium	7.50/9.50	12.00/16.00
Tungsten	—	2.00/4.00

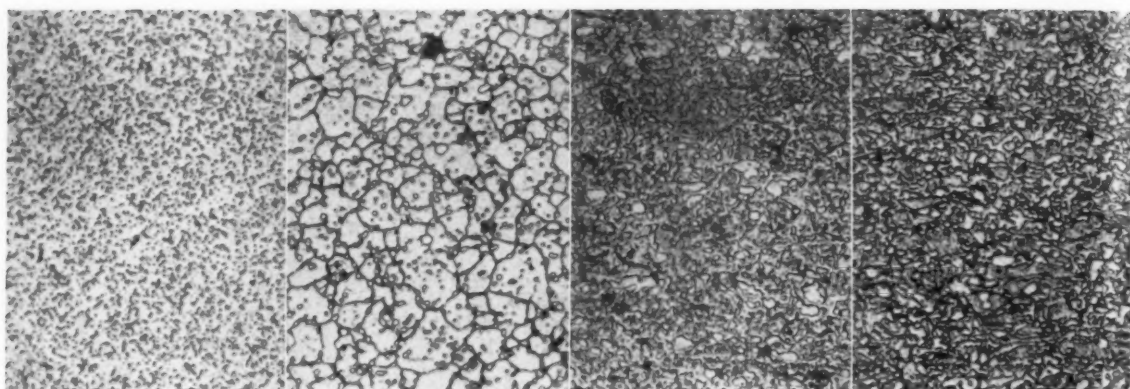


Fig. 8.—Silchrome No. 1. $\times 500$. Fig. 9.—Austenitic steel DTD.49B. $\times 500$. Fig. 10.—XB steel. $\times 500$. Fig. 11.—XCR steel. $\times 500$. Photomicrographs showing the structure of several valve steels.

Silchrome No. 1 was used in the bulk of their passenger cars in 1938, it was mainly replaced by the steels designated X.10, Sil-XB and XCR for exhaust valves in 1939⁷. The composition of the steels is given in Table V⁸ and it will be observed that X.10 is austenitic but XB and XCR are ferritic.

TABLE V.—COMPOSITION OF AMERICAN VALVE STEELS

	X. 10	XB	XCR
	σ_c	σ_c	σ_c
Carbon	0.30/0.45	0.60/0.85	0.40/0.50
Manganese .. .	0.80/1.30	0.20/0.60	1.00 max.
Silicon	2.50/3.25	1.25/2.75	1.00 max.
Chromium	17.50/20.50	19.00/23.00	23.30/24.30
Nickel	7.00/9.00	1.00/2.00	1.50/3.00
Molybdenum .. .	—	—	2.50/3.50

One advantage that both XB and XCR possess over the austenitic steels is their normal co-efficient of expansion; the values for this property are given in Table VI, together with the relative figures for Silchrome and Austenitic steel.

TABLE VI.—COEFFICIENT OF EXPANSION OF VALVE STEELS

Silchrome No. 1	12.8×10^{-6}
DTD. 49B	14.0×10^{-6}
XB	12.0×10^{-6}
XCR	14.1×10^{-6}

The author made an examination of both XB and XCR steel prior to the outbreak of war, with excellent results, although both were difficult to head by the electric upsetting process, and it was evident that in order to obtain the most satisfactory grain-flow they would have to be forged either by extrusion or gather-upset processes⁹. Both steels possess increased resistance to failure either by oxidation or lead attack, as shown by engine tests. The chemical analysis of the casts of steel used in these tests varied slightly from the limits quoted in Table V, although the deviations were not sufficient to affect the properties of the steel to any appreciable extent, as will be seen by reference to Table VII.

These casts of steel were of British origin, and supplies obtained were in the form of rolled bar, their structure as received consisting of spheroidal carbides in a matrix of ferrite and austenite.

7 "Valve Materials," Automotive Industries, November 19th, 1938.
8 "Valves and Valve Seat Materials," Metal Progress, October, 1943.
9 "The Trend in Poppet Valves," by A. T. Colwell, *J. Inst. S.E.E.*, 45, No. 1.

TABLE VII.—COMPOSITION OF XB AND XCR STEELS USED FOR TEST PURPOSES

	XB	XCR
	σ_c	σ_c
Carbon	0.76	0.42
Manganese	0.44	0.49
Silicon	2.19	0.52
Chromium	20.58	18.49
Nickel	1.53	4.72
Molybdenum	0.16	2.15

Both steels are of the hardenable type, XB by normal methods, and XCR by a precipitation treatment; XB can be hardened to a Rockwell of 50 C+ and XCR to 37/44 C, by a 14-hour temper at 790° C⁹.

XB is said to roll, forge and machine fairly readily, and this was borne out by the steel maker's report and the writer's own experience; XCR, however, is a difficult steel to work and machine and the forging temperature has to be held within very close limits.

XB Steel

Details of any heat treatment procedures which produce optimum properties in XB are scanty, although it is generally used in the normalised condition, the tips only being hardened; for that reason small samples of the hot rolled bar were subjected to various heat treatment procedures and then checked for hardness and micro-structure; the hardness test results are tabulated below in Table VIII.

The structure of all these specimens consisted of globular carbides dispersed in a matrix which is slightly darkened by the etching procedure, although it could not be resolved even at high magnifications. It is assumed, therefore, that the varying hardness of the matrix was due to precipitated carbides in a sub-microscopic form, the degree of precipitation and

TABLE VIII.—HARDNESS OF XB AFTER VARIOUS HEAT-TREATMENTS

Treatment	Hardness DH 30
As rolled	492
14 hours 760° C.—air cooled	325
20 mins. 950° C.—furnace cooled	348
20 mins. 950° C.—air cooled	393
20 mins. 950° C.—oil quenched	456
20 mins. 950° C.—oil quenched and tempered 800° C. .. .	359
20 mins. 1,020° C.—furnace cooled	343
20 mins. 1,020° C.—air cooled	423
20 mins. 1,020° C.—oil quenched	509
20 mins. 1,020° C.—oil quenched and tempered	458

coagulation of this carbide depending upon the heat treatment procedure. A typical structure is shown in Fig. 10.

The most suitable structural condition for a valve steel is probably that in which the carbides occur in a finely divided and highly dispersed form, in a matrix which will not undergo any appreciable transformation over the temperature range at which they operate in the engine, and which may fluctuate between 0 and 800° C. It is evident that this condition would be represented by the sample of XB treated for 14 hours at 760° C. and further tests were carried out to determine the structural stability of the steel when reheated for short periods at increasing temperatures after various heat treatments, the results of hardness tests being given in Table IX.

TABLE IX.—EFFECT OF RE-HEATING. HARDNESS AS DH/50

Steel	Silchrome 1	DTD 49B	XB		XCR
	1,050° C. O.Q. T890° C.	1,050° C. A.C.	760° C. 14 hours A.C.	950° C. O.Q. T890° C.	760° C. 14 hours A.C.
As heat-treated	290	208	316	342	464
Reheated to 800° C.	302	222	333	328	447
Reheated to 850° C.	277	201	318	328	386
Reheated to 900° C.	269	199	333	327	357
Reheated to 950° C.	261	211	317	323	269
Reheated to 1,000° C.	261	208	312	317	254

It will be seen that the treatment producing a condition entirely unaffected by subsequent heating is the prolonged soak at 760° C.; if considered necessary, the valve tip can be hardened by heating to 950/1,000° C. Valves tested in an engine after the low temperature treatment gave excellent results.

XCR Steel

The treatment given to this steel also consisted of a 14-hour soak at 760° C., this producing the structure shown in Fig. 11, comprising pools of austenite and globules of carbide in a martensitic type of matrix.

Reheating after heat treatment produces a progressive change in hardness when 850° C. is passed, probably owing to coagulation of these precipitated sub-microscopic carbides in the matrix; at 950° C. this change appears to be complete, the steel being in its softest condition—see Table IX. For ease of machining, it would appear advisable to soak this steel at a temperature of 950/1,000° C. for a short time, followed by air cooling, and to subsequently harden at 760° C. prior to final grinding.

There is little doubt that the high hardness of this steel is effective in preventing dislodged particles of solid deposits becoming embedded on the valve seat, although its main property is of course, its resistance to oxidation. Engine tests with leaded fuel showed it to possess reasonable life.

Present Supplies of XB Steel

Determination of the metallurgical properties of XB steel now available is of interest, and shows considerable progress on the part of the steel makers. The composition is in general accordance with the limits given below, but there is still an absence of information on recommended heat treatment procedures.

Carbon	0.74/0.84%
Silicon	1.75/2.25
Manganese	0.20/0.60
Nickel	1.15/1.65
Chromium	19/20.5
Sulphur	0.03 max.
Phosphorus	0.03 max.

The majority of the valves produced in this steel have been heat treated either by:—

(a) Oil quenching from a temperature between 1,000 and 1,050° C., followed by tempering at a temperature between 700 and 850° C., or:

(b) Air cooling from a temperature between 800 and 860° C. followed by tempering at between 700 and 780° C.

These treatments may be followed by local hardening of the tip of the stem.

The mechanical properties of two samples after various treatments have been determined; the heat treatment procedures are given in Table X, their composition in Table XI and properties in Table XII.

TABLE X.—HEAT-TREATMENT PROCEDURES

Ident	Heat-treatment Procedure
1	Heated 1 hr. at 1,050° C.; tempered, 800° C. and air cooled
2	Heated 1 hr. at 860° C.; air cooled; tempered, 740° C.
3	Heated 1 hr. at 800° C.; air cooled; tempered, 740° C.

TABLE XI.—CHEMICAL ANALYSIS OF SAMPLES

Sample	Supplier	
	A	B
Carbon	0.81	0.84
Silicon	1.24	2.14
Manganese	0.63	0.53
Nickel	1.26	1.57
Chromium	20.82	20.00
Molybdenum	Trace	NH
Sulphur	0.022	0.021
Phosphorus	0.032	0.015

TABLE XII.—MECHANICAL PROPERTIES AFTER TREATMENT—IMPACT TESTS MADE ON IZOD MACHINE USING 8 MM. DIAMETER SPECIMEN (UNNOTCHED)

Sample Treatment	A			B		
	1	2	3	1	2	3
Ultimate Strength—tons/sq. in.	72.96	67.84	67.68	64.64	60.16	61.0
Impact Value—ft./lb.	60	59	55	40	40	46
Hardness—DH/50	370	360	325	340	309	318

The similarity of the mechanical properties for each supply of steel with such different heat treatment is interesting and evidently explains the absence of published information giving recommended procedures.

Comparison of Available Steels

The strength of the four steels discussed are summarised in Table XIII and it will be seen that XB is mechanically superior to XCR and is little different to Silchrome No. 1, although it is slightly less ductile.

Reference has previously been made to the structural stability of certain of these steels—see Table IX; their comparative resistance to oxidation was determined by heating small cylinders of each in a free atmosphere of air for six hours at 900° C. with the results given in Table XIV.

The XB and XCR steels possess equal resistance to oxidation under the conditions of test, and both are

TABLE XIII.—MECHANICAL PROPERTIES OF VALVE STEELS (IMPACT VALUE DETERMINED ON UNNOTCHED SAMPLES 8 mm. DIAMETER)

	Silchrome No. 1	DTD. 49B	XB	XCR
Yield Point—tons/sq. in.	46	28	56	—
Ultimate Strength—tons/sq. in.	58	51	65	86
Elongation—%	32	39	13	4
Red. of Area—%	58	48	25	—
Impact Strength—ft./lb.	73	50	50	8
Hardness—DH/50	290	208	320	464

TABLE XIV.—OXIDATION EXPRESSED AS MGMS. PER SQ. CM.

	Silchrome No. 1	DTD. 49B	XB	XCR
Oxidation	39	11	20	19

very much superior to Silchrome No. 1; the austenitic steel is of course, the best.

The hot hardness of these four steels is given in Table XV⁸; XCR and DTD.49B have the highest hardness at the maximum operating temperature, but XB shows considerable improvement over the normal Silchrome steel.

TABLE XV.—HOT HARDNESS AS DH/50

	Silchrome No. 1	D.T.D. 49B	XB	XCR
Normal Temperature	250-390	240	386	415
At 500° C.	169-179	165	254	239
At 800° C.	14-20	53	26	63

Conclusions

The properties required in an automobile exhaust valve steel are well known, and have been ably summarised by Aitchison¹⁰ and Boegehold and Johnson.¹¹ From the experience of the automobile industry, the

ideal material for exhaust valves has yet to be discovered; although new materials are available, they cannot be regarded as showing any considerable improvement over Silchrome No. 1, with the exception of the sodium cooled austenitic steels. The problem in relation to leaded fuel should be regarded as one of unsatisfactory combustion rather than faulty metallurgical technique, for so long as actively corrosive products are formed during combustion and deposited in the combustion space is the problem bound to be with us; while it is essential to raise the octane rating of fuel to the highest possible level in accordance with progressive engine design, and so long as this effect is obtained by the use of additives, trouble can be expected until such time as the harmful compounds produced on combustion can be satisfactorily evacuated as an entirely gaseous product. It is claimed therefore, that the problem is one for the fuel technologist rather than for the metallurgist, although the closest co-operation between the engine designer, metallurgist and fuel technologist is vital if the demands for ever increasing engine efficiency are to be met.

¹⁰ *Proc. Institute Automobile Engineers*, 1920, Vol. 14, p. 30.

¹¹ "Engineering Requirements in the Automotive Industry for Metals operating at High Temperatures." *American Society of Mechanical Engineers and A.S.T.M. Symposium on Effect of Temp. on the Properties of Metals*, June 1931, pp. 170-191.

Carbon-Molybdenum Steel for Steam Pipes

By L. Rotherham, M.Sc., F.Inst.P.

THE standard material for steam power plant in greatest use in the past has been carbon steel, and, over many years, experience of this material has become very extensive. Laboratory investigations into the properties of typical carbon steels used in power plant have been conducted at the same time, and form a satisfactory background to the accumulated experience of the material to give a reasonable degree of certainty in the use of carbon steels in higher ranges of temperature than formerly. The trend towards highly efficient stations working at higher steam temperatures and pressures than were common a few years ago is likely to continue, and it will be useful to consider first how far carbon steels will be regarded as satisfactory in the future.

When the service temperature is high enough for creep to become important, say at 700° F. for carbon steels, it is generally true that the load carrying ability of the material falls rapidly, and a temperature may be reached where it is no longer economical to use a carbon steel. This will be obvious when it is pointed out that the creep stress for a given deformation per cent. in a given time of an alloy steel at 900° F. may be double that of a carbon steel, so that the actual weight of material in a component may be only a half of that required in a carbon steel. Many other factors enter into the choice of material for high temperature service, such as fabrication costs, but on the whole it is probably true that for the highest temperatures, say 850° F. and upwards, many advantages can be gained by the use of

alloy steels, and even at lower temperatures there will be cases where greater use can be made of alloy steels.

Carbon-molybdenum steel has been in the past perhaps the most important material for use in steam pipes instead of carbon steels, and a consideration of its properties in relation to other alloy steels and to carbon steel may be of interest.

A wide list of properties could be drawn up to illustrate the suitability of a material for high temperature service. In the main, however, the assessment can be

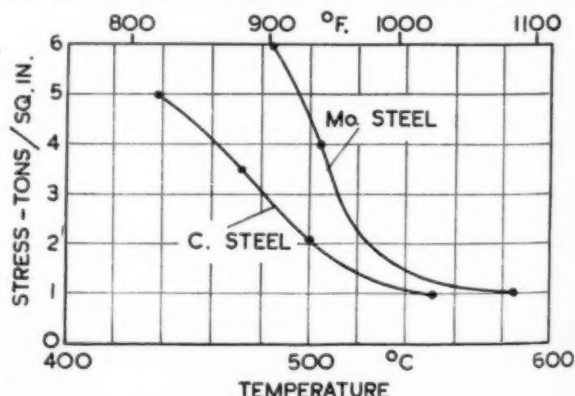


Fig. 1.—Comparison of carbon and carbon-molybdenum steel steam pipes—stress for 0.1% deformation in 100,000 hours.

based on resistance to deformation, resistance to oxidation or corrosion, and satisfactory stability of structure. In addition the material must be satisfactory for production at a reasonable cost, with facilities already available, and must be satisfactory for welding and manipulation in installation. For welding, a minimum alloy addition may be regarded as desirable, and in this respect carbon-molybdenum steel is perhaps the nearest approach to carbon steel. In fact, large quantities have been assembled by welding.

If the cold mechanical properties can be regarded as a criterion of the suitability of the material for production and manipulation a direct comparison can be made between carbon steel and carbon-molybdenum steel:—

MECHANICAL PROPERTIES OF STEAM PIPE MATERIALS

	Carbon Steel	Carbon-Molybdenum Steel
Limit of Proportionality (tons/sq. in.) ..	17.7	14.5
Yield Point (tons/sq. in.)	19.3	15.6
Maximum Stress (tons/sq. in.)	27.0	27.0
Elongation %	45.0	36.0
Reduction of Area %	70.0	45.5

These results are taken from publications by Tapsell and his colleagues^{1,2}, and it may be noted that the carbon-steel steam pipe was of 10½ in. o/d and ½ in. wall thickness, and was of 0.135% carbon content, while the carbon-molybdenum steel was from a pipe of 13 in. o/d and 1.95 in. wall thickness, and contained 0.09% carbon and 0.50% molybdenum. It will be noted that these results, considered to represent typical steam pipes in the two materials, are very similar.

Short-time tensile tests, giving the limit of proportionality, proof stress or maximum stress, are now generally discredited as means of assessing the suitability of a steel for high-temperature service. Some use can be made of short-time creep tests, particularly to assess the quality of a material of known type, but in general, long-time creep tests are necessary for deciding the working stresses to which a material may be subject in service. Even here an element of doubt may be encountered, since it is uncommon for tests of more than about 10,000 hours to be carried out, whereas the life of steam power plant may well be more than ten times this amount.

For the carbon-molybdenum steel referred to above, Tapsell and Ridley² carried out creep tests under 1, 2, 4 and 6 tons/sq. in., at temperatures ranging from 550° C. (1,022° F.) to 700° C. (1,292° F.), and for times in some cases in excess of 5,000 hours, in an attempt to estimate working stresses. Similar test results for carbon steel were already available, in a previous paper by Tapsell¹, and a comparison can be made of the two materials, and is shown in Fig. 1, which shows the stress for 0.1% creep strain in 100,000 hours at various temperatures. It can be seen that if this criterion be accepted as a basis for design, the carbon-molybdenum steam pipe will carry roughly double the stress of the carbon steel at 900° F. Alternatively, it can be said that if the working stress is 5.0 tons/sq. in., the carbon steel can be used at temperatures up to 800° F., while the carbon-molybdenum steel will carry the same load at a temperature in excess of 900° F.

It must be recognised, however, that both carbon steels and carbon-molybdenum steels of a given analysis

are not uniform in resistance to creep (see the section on "abnormal" carbon steels in Tapsell & Johnson—*Proc. Inst. Mech.E.*, 1941, Vol. 144, p. 97). Some regard must be paid to the likelihood of a material below normal in creep resistance being encountered, and also to the greater past experience of carbon steels. With this in mind, it is reasonable to take the stress for an 0.1% creep deformation in 100,000 hours as a working stress for a molybdenum steel, while a stress giving a rather higher deformation might be tolerated in a carbon steel. The superiority of molybdenum steel over a carbon steel in resistance to creep, and therefore, in suitability for carrying a load in service, is roughly indicated in Fig. 1, however, and in terms of temperature can be expressed as follows: The working stress for a carbon steel at 800° F. is about the same as that of a carbon-molybdenum steel at 900° F.—i.e., an advantage of 100° F., and the working stress of a carbon steel at 900° F. is about the same as that of a carbon-molybdenum steel at 950° F.—i.e., an advantage of 50° F.

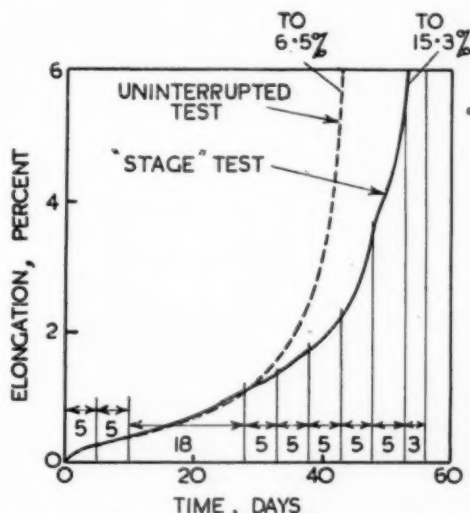


Fig. 2.—"Stage" test compared with an uninterrupted creep test of carbon-molybdenum steel. From Tapsell, Bristow and Jenkins.

In considering the performance of the two materials, some regard must be paid to ductility, and it is interesting to note that in a test fractured in 1,830 hours, under 6 tons/sq. in. at 1,067° F. (575° C.) Tapsell² records only 5.5% elongation, whereas he gives a 20% creep in 1,000 hours for a carbon steel tested under 5.0 tons/sq. in. at 1,022° F. (550° C.). Similarly, an American source of data³ records 5.0% elongation at fracture in 1,174 hours, in a test carried out at 1,000° F. under a load of 9.4 tons/sq. in.

Attention to the question of ductility has been given in a further excellent paper from the National Physical Laboratory, by Tapsell, Bristow and Jenkins⁴, in which tests are described on carbon-molybdenum steel bar of substantially the same analysis as the steam pipe already referred to. The illustration shown in

² Tapsell and Ridley, *Proc. Inst. Mech.E.*, 1945, Vol. 153, p. 181.

³ Digest of Steels for High-temperature Service, Timken & Co.

⁴ Tapsell, Bristow and Jenkins, *Proc. Inst. Mech.E.*, 1942, Vol. 146, p. 208.

¹ Tapsell, *Proc. Inst. Mech.E.*, 1944, Vol. 151, p. 54.

Fig. 2, taken from this paper shows a comparison between an uninterrupted creep test under 7.0 tons/sq. in. at 580°C. and a similar test in which a periodic examination was made of the microstructures of the material. It will be noted that both tests enter the third stage of creep at roughly the same time of about 28 days, and at an elongation of about 1%. At this time, the description of the microstructure was as follows—"many of the transverse boundaries appeared to be thicker than the longitudinal." The further evidence recorded at later times tended to confirm that this was the beginning of intercrystalline cracking, which is the typical mode of failure of this material under creep conditions. The final elongation in this test was 15.3%, so that most of the elongation occurred after the material had reached a most dangerous condition.

Recognising that the total elongation may be as low as 5.0% at fracture, it could not be safely assumed that the material would be free from incipient cracking if the creep deformation were much in excess of 0.1%. In addition it is worth noting that too much attention should not be paid to the values of total elongation recorded in tests to fracture under creep conditions, for the material may be in a dangerous condition at amounts of creep certainly as low as one-fifteenth of the total elongation. In considering substitute material for carbon steels and carbon-molybdenum steels for high temperature service, this is often overlooked.

Particular attention has been given above to the ductility of the carbon-molybdenum steel for steam pipes, since this may be one property of the material which is related to the isolated cases of cracking which have been encountered in power stations in this country. This cracking appears to be a distinctly different phenomenon from that encountered in the United States, and very much less serious in its nature.

It is now fairly well known that the cracking which has occurred has been usually associated, as might be expected, with regions of stress concentration, or of local damage. Little is known of the effects of notches on the creep strength and ductility of materials at high temperatures, but it will be agreed that account must be paid to the possibility of the effects being bad. Furthermore, oxide penetration or rooting, which is sometimes practically unavoidable, may be considered to provide notches where no others are present. The only conclusion which can be reached on present evidence is that a material with a high ductility before cracking (i.e., not necessarily a high total ductility) is to be preferred to one of low ductility, and that stress raisers should be avoided.

A second factor which must be taken into account is the possibility of internal stresses left in the fabrication or installation of the pipes. If bending of the pipes cold, or similar deformation is resorted to, internal stresses comparable in magnitude with the yield point of the material may result. If stresses of this order, say 15 tons/sq. in., existed in the pipe, a creep deformation of the order of 0.1-0.15% would be necessary for the relief of the stresses, and this might be comparable with the total safe deformation of the material. Usually, such internal stresses would be eliminated by a full normalising treatment, which, if carried out so that the introduction of thermal stresses was avoided, would result in a virtually stress-free pipe, but occasionally sub-critical stress-relieving treatments must be used.

One point which has not been satisfactorily settled is whether or not the permissible creep deformation of the material is as high when stresses are relieved in the sub-critical range of temperatures by what is a process of creep, as when a full normalising is resorted to.

Little attention need be given to the surface stability of carbon-molybdenum steel. In a lengthy study on unstressed materials Rohrig, Van Duzer and Fellows⁵ carried out tests up to 16,000 hours in a steam atmosphere at temperatures from 925°-1,100°F., and established that carbon-molybdenum steel has a resistance to attack comparable with that of carbon steel.

Changes in microstructure are more important. Tapsell, Bristow and Jenkins⁶ reported that generally it was possible to detect spheroidisation of carbide in creep-test specimens after the completion of test, but normally the tests had been carried to the point where intercrystalline cracking had begun. In other words, spheroidisation was observed after the material had passed the end of its useful life. Graphitisation on the scale noted in reports from the U.S.A. was not observed, and if present at all must have been very slight.

It would be easy to dismiss graphitisation from our considerations if the extensive nature of the trouble in the U.S.A. did not suggest that it is a most serious matter. Fortunately, this subject has been very extensively investigated, and a number of important conclusions reached. For instance, Hoyt and Williams⁶ report that carbon steels graphitise more easily than molybdenum steels, and that only those steels deoxidised with a considerable addition of aluminium showed graphitisation. This is substantially in line with the conclusions of Kerr and Eberle⁷, with the additional recommendation that the addition of 0.4-0.6% of chromium is advantageous for high temperature services. The use of aluminium for deoxidisation is not uncommon in this country, but it is usually used in much smaller quantities than is common in the U.S.A., which may account for the freedom from the trouble of graphitisation in this country. It also points to the fact that alloys of the same nominal composition made in the U.S.A. or here are not the same materials by any means, and although the 0.4-0.6% chromium addition to the molybdenum steel has been considered and used in this country, its proved value for high-temperature service must await further experience and tests.

Conclusions

In relation to carbon steel, the carbon-molybdenum steel has very advantageous creep resistance in the higher steam temperature ranges, which in combination with its other properties suggest that it can be of definite value for steam piping. On the other hand it has a lower ductility, which makes it essential that care should be exercised in its fabrication and installation. While graphitisation has not been proved to occur in pipes of British manufacture, the American experience suggests that care in the production of the material should be extended back to the melting process.

The incorporation of 0.5% chromium in the carbon-molybdenum steel is a possible line of future development, which will be better established when further experience has been acquired.

⁵ Rohrig, Van Duzer and Fellows, *Trans. A.S.M.E.*, 1944, Vol. 66, p. 277.

⁶ Hoyt and Williams, *A.S.M.E. Journal*, 1945, Vol. 24, p. 274.

⁷ Kerr and Eberle, *A.S.M.E. Welding Journal*, 1945, Vol. 24, p. 86.

Modern Methods of Gas Analysis

Part V.—The Bone and Wheeler Apparatus

By W. D. Vint

The Bone and Wheeler apparatus for the examination of gases is described. In addition to the standard laboratory apparatus, reference is made to a modified form for analysing mine gases and a portable form for the analysis of exhaust gases; with a slow burning attachment it is applied to the analysis of more complex gases.

THE Bone and Wheeler apparatus, shown in Fig. 1, is a standard form of gas testing instrument and is generally accepted by most laboratories as suitable for the examination of gases of widely differing composition. Besides the standard laboratory apparatus (applicable to the analysis of illuminating and heating gases) there is the modified form with which it is possible to analyse mine gases and the portable form for the analysis of exhaust gases. With the addition of a slow burning attachment to the ordinary Bone and Wheeler, it is possible to analyse some of the more complex gases.

Description

The apparatus consists of three parts:—

1. Water jacketed graduated U tubes for the confinement and measurement of the gas.

2. An absorption vessel over mercury in a trough connected to the gas burette by capillary tubing.

3. An explosion vessel.

Mercury is used as a confining liquid throughout, the level of which can be easily read with the help of a horizontal brass tube containing a magnifying glass and the illuminated glass ground glass screen situated behind the water jacket. The water jacket, provided with inlet and outlet tubes is kept supplied by a constant flow of water at even temperature from an indoor water tank. If the latter is unobtainable, a large aspirator fitted with some form of constant level device may be used satisfactorily. The temperature of the water in the jacket can be noted at any time from the thermometer mounted at the top.

The U tube is supplied with mercury from the reservoir "C," the carrier of which can be raised or lowered by operating a winder fitted with a retaining pawl. The operation of tap T2 controls the flow of mercury. An

additional slow control may be obtained by bringing only the notch of the tap into communication with the U tube and the reservoir.

Measurement of the Gas

Unlike the Orsat apparatus, measurements are made on the constant volume, varying pressure principle. As each constituent of a gaseous mixture is absorbed, the pressure is lowered to an extent proportional to the volume of the constituent. In every case, after an absorption has been made, the height of the confining column of mercury is adjusted to a constant and previously selected mark on the limb of the measuring tube. Gas pressures are indicated by the height of the column of mercury which the gas supports in the limb B of the U tube which is 800 mms. long and graduated at every mm. The limb A is graduated regularly only at intervals corresponding to 100 mms. pressure; these markings correspond to the 100 mm. markings on the other limb B. Should the sample of gas be small, a high graduation mark on A is selected and is called the constant volume mark.

The actual measurement of gases is made by moving the horizontal tube containing the magnifying lens along a vertical brass rail fixed to a wooden stand.

Gas Absorbent Reagents

The reagents are similar in strength to those used in the Orsat apparatus. For CO_2 , KOH solution; O_2 , alkaline pyrogallol; benzene and higher olefines, concentrated sulphuric acid;

CO, ammoniacal cuprous chloride solution.

Combustion Apparatus

The explosion tube D is connected to the capillary system by a T branch

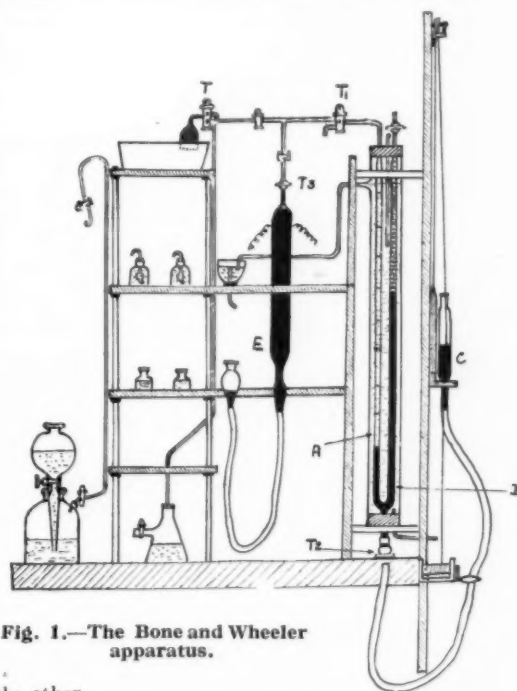


Fig. 1.—The Bone and Wheeler apparatus.

and may be isolated by the tap T3. The tube is provided with platinum contacts near the top of the wider portion and are connected to the secondary winding of an induction coil. The latter may be powered by a six volt battery or a step down mains transformer. The confining liquid is mercury and the lower end of the explosion tube is connected to a reservoir which can be placed at various positions on the stand to vary the pressure inside the tube.

A copper oxide combustion tube inside a furnace is necessary if paraffin hydrocarbons other than methane are

present in a gaseous mixture. Connections from the combustion tube are made to the measuring tube and pipette with mercury reservoir.

Preparation of the Apparatus for Use

All the interior surfaces of each part of the apparatus must be moistened with water acidulated with H_2SO_4 . All taps must be cleaned free from chemicals or gritty matter, and smeared lightly with tap grease. Mercury is added to the reservoir and about 20 cc. of acidulated water is added to the absorption vessel and tap T1 closed. Taps T and T3 are opened and the acidulated water flows into the combustion pipette; after closing T3, raise and lower the reservoir to moisten the walls of the vessel.

The excess of acidulated water in the measuring tube may be removed by dropping the mercury below the junction of the two tubes; close tap T2, raise the reservoir and then open tap T2 sufficiently to allow mercury to flow into the measuring limb very slowly. The acid can now be removed and the apparatus is ready for use.

A vacuum reading should first be made. An appropriate graduation mark is chosen on the limb A according to the quantity of the sample of gas available—if the sample is small, a high graduation mark is selected, if large, a low graduation mark is taken. Close taps T2 and T and with the mercury reservoir in a low position, tap T2 is opened and the mercury levels in the two limbs allowed to fall below the graduation mark. Close tap T2 and raise mercury reservoir. Mercury is now allowed to flow into the two limbs until the mercury meniscus in the limb A coincides exactly with the correct graduation mark. Tap T2 is now closed and the reading in limb B recorded. A check up on the possibility of traces of air or incorrect alignment of the measuring tube can now be made by a comparison of the readings

in A and B. Differences, however small, must be noted and the necessary correction applied to the calculation of the gas analysis.

For example, should the vacuum reading be say 299.7 mms. when the 300 mm. graduation has been selected on A, then for a volume of gas whose pressure in limb B is 662.3 mms., the real pressure is $662.3 - 299.7 = 362.6$ mms. The limbs A and B can now be filled with mercury again.

Procedure for Analysis

The sample of gas is introduced into limb A through the inlet to the capillary of tap T1, after making sure that all air is swept from the top capillary by filling with mercury. The pressure of the gas in A may now be measured to the constant volume mark in a similar manner as employed in making a vacuum reading. The temperature of water in the jacket is noted. The absorption bulb is filled with mercury and two to five mls. of reagent added by means of a pipette. The small amount of mercury which may be left at the bottom of the upturned part of the pipette must be blown into a separate waste bottle which is kept for this purpose. The gas is now transferred to the absorption vessel by raising reservoir C to bring about a slight pressure in the limb A and opening taps T2, T1 and T (reagents can be prevented from entering the limb A by ensuring that there is a pressure in A before opening taps T1 and T). The capillaries must be swept clear of gas by allowing mercury from the reservoir to follow through until a small quantity enters the absorption vessel. Tap T is now closed and the stand gently tapped to bring the gas into intimate contact with the reagent (no reagent should be allowed to touch the end of the capillary). When absorption is considered complete, open tap T and allow a small quantity of mercury to flow into the absorption vessel to clear the capillary exit of any reagent which may have collected there.

With tap T closed, the mercury reservoir is now lowered and the lowest possible vacuum maintained in limb A to permit withdrawal of the gas. The withdrawal may be set at a low rate by manipulating the tap T2 to bring in the slow running notch. When the level of the absorbent in the capillary reaches the tap T, the latter is turned to enable the reagent to escape to waste. No reagent must be allowed to pass the top of the capillaries. The mercury in the absorption vessel must now be washed with dilute H_2SO_4 , the liquid and air are then blown to waste and the mercury is brought to the correct level beyond the tap T1. The pressure of the gas in limb A is now noted after it has been brought to the constant volume mark. The temperature of the jacket is noted and any temperature correction necessary is now applied. Gases are absorbed in the same sequence as in the Orsat Apparatus, i.e., CO_2 , O_2 , unsaturated hydrocarbons, CO.

After the absorption of the unsaturated hydrocarbons, the gas is returned to limb A and the mercury washed once or twice with water. Air is then blown on to the surface of the mercury to clear the skin which has formed. Caustic potash is added and the gas passed from the measuring limb into the absorption vessel. When the bromine fumes have been removed from the gas, the latter is returned to the measuring limb and the absorption vessel washed with dilute H_2SO_4 .

A measurement of the gas pressure and water jacket temperature is now made. The gas is now passed back into the absorption bulb and two to five mls. of ammoniacal cuprous chloride solution added. After the absorption of CO (which, incidentally,

$$O_2 \text{ is } (354.6 - 338.4) \times \frac{100}{354.6} = 4.6\%$$

$$O_2 \text{ is } (338.4 - 336.9) \times \frac{100}{354.6} = 0.4\%$$

$$COHm \text{ is } (336.9 - 324.5) \times \frac{100}{354.6} = 3.5\%$$

$$CO \text{ is } (324.5 - 297.2) \times \frac{100}{354.6} = 7.7\%$$

$$CH_4 \text{ is } \frac{15.6}{57.2} \times \frac{297.2}{354.6} \times 100 = 22.9\%$$

$$H_2 \text{ is } 2/3 \times \frac{87.7 - 2 (15.6)}{57.2} \times \frac{297.2}{354.6} \times 100 = 55.2\%$$

N_2 is obtained by difference.

Complete analysis of gas is therefore:

CO_2	..	..	..	..	4.6%
O_2	..	..	..	..	0.4%
$COHm$	..	..	..	..	3.5%
CO	..	..	..	..	7.7%
CH_4	..	..	..	..	22.9%
H_2	..	..	..	..	55.2%
N_2	..	..	..	..	5.7%
					100.0%

(SAMPLE OF COKE-OVEN GAS FROM VERTICAL RETORT)
TYPICAL CALCULATION

Absorbents Used	Vacuum Reading V	Pressure P	P-V	Temperature	Corrected Pressure Difference
Gas	199.7	554.3	354.6	20.3	354.6
KOH	199.7	538.1	338.4	20.3	16.2
Pyrogallol	199.7	536.6	336.9	20.3	1.5
Bromine solution	199.8	524.3	324.5	20.3	12.4
Cuprous chloride	199.8	597.0	297.2	20.3	27.3
Gas take for explosion	199.8	557.0	57.2	20.3	57.2
Air for explosion	200.0	561.0	361.0	20.3	301.0
Gas/air mixture	200.0	558.2	358.2	20.3	358.2
After explosion	200.0	470.5	270.5	20.3	87.7
After KOH	200.0	454.9	254.9	20.3	15.6

requires two separate portions of reagent) the gas is returned to the measuring limb, and the absorption vessel washed with water and then dilute H_2SO_4 . Ammonia which may be present in the gas from the ammoniacal cuprous chloride can be removed by adding a small amount of dilute H_2SO_4 .

Assuming now that the residual gas consists solely of methane, hydrogen, and nitrogen, a suitable portion is taken with the appropriate amount of air or oxygen and exploded in a similar manner to that employed by the Orsat apparatus. Gas measurements are taken of (1) the residual gas for explosion, (2) the gas plus air, and (3) the contraction after explosion. The CO_2 formed by the explosion is absorbed in the absorption vessel in

KOH as usual and the final gas measurement taken.

Throughout the whole of the analysis at each gas measurement, the water jacket temperature is taken. The air or oxygen added for explosion purposes may be introduced through the tap T1 and it should be arranged that the mixture in the absorption vessel is exploded at a pressure of about half an atmosphere. At the completion of the explosion, the reservoir C is placed at a point about midway along the slide and the products of the explosion transferred to the limb A by means of the reservoir attached to the explosion tube.

Modified Procedure for Residual Gases Containing Higher Paraffin Hydrocarbons

The treatment for such gases involves the removal before explosion

of the hydrogen. This may be done in several ways, and the two most common methods are:—

1. By passing the gas over heated palladised asbestos or palladium black,
2. By passing over heated copper oxide.

The latter method can be most readily applied to the Bone and Wheeler apparatus. The copper oxide may be contained by a silica tube which is heated to a temperature of 280 degrees C, and the gas passed through for a period of about 15 minutes. Successive pressure readings taken on the burette indicate whether or not the whole of the hydrogen has been absorbed. When the gas has been returned to limb A the diminution in pressure is measured and from this is calculated the volume and hence the percentage of hydrogen.

Induction Brazing

By R. Baubie

INDUCTION brazing, using practically the full range of solders and brazing alloys, fused by electrically induced heat, promises to take an important place in the fabrication of metal parts as a result of its unequalled advantages in speed, simplicity of operation, and precise control of variables. This joining method uses brazing materials varying from soft lead solder with a melting point of approximately 205° C. to pure copper with a melting point of 1,084° C. Probably no fabrication process offers greater advantages to the designer in improvement of the finished product and reduction of manufacturing cost by lowering the number of rejects and the development of largely automatic production processes.

The process itself is not over-complicated. The parts to be joined are placed in position, a predetermined amount of braing alloy is placed at the joint after application of the flux, and the alloy is fused by the application of induction heat. Precision manufacture is possible through characteristics common to all brazing alloys, namely, that all are free flowing in correct temperature ranges, and produce a strong joint with a clearance between parts of as small as 0.001 in. In induction brazing all grease must be removed and a clean, bright metal

surface obtained before the flux is applied, and the brazing alloy chosen must have a lower melting point than either of the pieces to be brazed. Steel and aluminium parts cannot be brazed by copper.

The most familiar forms of brazing metal used in induction brazing are silver solder and a brass composition containing varying amounts of silver. More than a dozen alloys, with composition varying according to use are available. All have one characteristic in common in that they have melting points below the more common metals being joined, which have melting points varying from, approximately, 600° to 1,425° C. One of the more recent developments is an aluminium base solder. Solders of this type have a flow point of 290° C. and have an affinity for almost any metal. Experiments have been conducted with this solder in joining aluminium to copper and to cast iron, to soldering magnesium alloys, and to joining other metals to these and also in soldering many grades of white metal and die cast white metal.

Control of variables is one of the most important advantages gained by automatic over manual operation. Variables in brazing are generally heat, time and amount of brazing alloy used. Heat control involves temperature, length of time heat is applied and depth of penetration.

Induction heating meets all these requirements, with accurate control and precise timing from 1/60 sec. to 5 min. or more. The amount of brazing alloy is controlled by using pre-cut pieces, usually from wire or flat stock. When brazing is combined with hardening, quenching is likewise automatic, with precise regulation of temperature and amount, using hot or cold water, oil or whatever quenching liquid may be indicated. By predetermined control of heat and quenching, it is also possible to combine with the brazing operation either hardening or annealing the piece in production.

The wide range of products that can be made by induction brazing includes small crankshafts, attaching shanks to drills and reamers, fastening lugs to hose clamps, fastening carbide tips to cutting tools and making hydraulic, pneumatic and refrigerator fittings. Coil design and the design of jigs and fixtures are important factors in induction brazing, and one of the newest developments is the use of interchangeable coils or inductors which can be changed as readily as drills or reamers for different jobs, and jigs and fixtures likewise designed for individual jobs and readily interchangeable.

STEELS IN GERMAN AIRCRAFT.

SOME copies of the above book are still available. Order direct from The Kennedy Press Ltd., 31, King Street West, Manchester, 3, enclosing 10s. 6d.

From *Materials and Methods*, 1946, Vol. 23, No. 4, pp. 1097-1010.

The British Iron and Steel Industry

(Continued from page 136)

While these and other extensions are in hand large central engineering workshops are being provided. These are sited between the reconstructed rolling mills and the Appleby melting shop, and site clearance, excavations and foundation work are far enough advanced for it to seem reasonable to hope that the workshops may be completed during the first half of 1948.

There is history behind the £260,000 reconstruction of Richard Johnson and Nephew's continuous rod mill, which it is hoped to complete by this autumn. The first continuous rod mill to be put into operation anywhere was patented, designed and built in 1865 by George Bedson, works manager of Richard Johnson and Nephew, Ltd., and grandfather of N. P. Bedson, present designer and chief engineer at Bradford Ironworks. The mill was installed at an old silk mill in Salford and transferred to Bradford Ironworks two years later. At this time, Bradford Ironworks was equipped with 13 furnaces for making puddled iron and the rod mill ran there for nearly 20 years. It is interesting to record that a duplicate of the second mill designed by George Bedson and built at Bradford Ironworks was installed in America, at Washburn and Moen's Works, at Worcester, Massachusetts, in 1869, and introduced the continuous rod mill to that country.

The present developments are thorough-going and involve alteration or replacement at every stage throughout the mill. As ever, it has been imperative that current production should not be impeded and only the very last stage (the installation of new roughing stands and alterations to the preheating furnace) will interrupt output. Already in operation are a new Wood's gas-producing machine with an input of about 2½ t/hr. of coal and the 4 semi-finishing and 6 finishing stands (Nos. 9 to 18) of the new layout with coilers and conveyor mechanism for cooling. Through the new stands one string is being put from the present 8-stand roughing mill, giving a speed of about 2,900 ft./min. against the ultimate speed of 4,000 ft./min. which will be achieved when the installation is completed and two strings are running through. The mill output is then expected to be in the neighbourhood of 2,000 t/wk, about double its previous capacity.

The new installation is a straight through mill, replacing the old mill with two separate finishing trains, one on each side of the roughing train, running parallel and in the reverse direction to it. It is because of this that it has been possible to instal the new semi-finishing and finishing train without disturbing the present arrangements. The new roughing and intermediate stands, however, cannot be erected before the present stands are removed. There will be a total of 19 stands: Nos. 0-6 roughing; 7 and 8 intermediate; 9 to 12 semi-finishing and the remainder finishing. Stands 0-8 will have 13-in. diameter rolls, the remainder 10 in. In the arrangements for driving power will come from two motor generator sets, normally running in parallel, but capable of being split.

It has only been possible to give a few examples of the reconstruction and modernisation work, completed, in progress, or planned, indicating two or three iron and steel works, but these can be regarded as typical of the activities at the various producing centres throughout the

country. That success will attend the efforts to step up production there need be no doubt and in a relatively short time the efficiency of this country's iron and steel industry and the quality of its products will compare favourably with those of any other country.

Correspondence

Developments in the Application of Controlled Atmospheres

The Editor, METALLURGIA.

Dear Sir,

In the interesting article by Mr. Jenkins on the above subject in your May issue, there is a description of the sodium hydride de-scaling process which may convey a wrong impression.

The sodium hydride process is a method of de-scaling steel without attacking the under-lying metal, and it depends on the chemical reduction of the oxide scale to powder metal by the action of sodium hydride which is present to the extent of about 2% in a bath of molten caustic soda held at a temperature of 350°-370° C. The function of the cracked ammonia is not to provide a controlled atmosphere in the usual sense of the term, but it is used merely as a convenient source of hydrogen which reacts with sodium in a specially designed generator to form sodium hydride which goes into solution in the bath of molten caustic soda. The articles to be de-scaled are immersed in the melt for a short time and are then quenched in cold water, which has the effect of removing most of the reduced scale from the surface.

The sodium hydride process has no connection whatever with de-enamelling which is carried out in a bath of molten caustic soda at 450°-500° C. without the necessity of using sodium hydride so that in this case cracked ammonia is not used at all.

Yours faithfully,

Imperial Chemicals Industries, Ltd.

(N. L. EVANS, B.Sc., F.R.I.C., F.I.M.)

for Alkali Division, Technical Service Manager.

Northwich, Cheshire.

June 19th, 1947.

The Editor, METALLURGIA.

Dear Sir,

I am grateful to Mr. Evans for removing any misunderstanding which may have arisen from my reference to the descaling and de-enamelling processes. Although of interest to those who are engaged in heat-treatment in controlled atmospheres, these processes did not come strictly within the scope of the subject of my article; hence, my reference to them was, perhaps, a little too brief.

Yours faithfully,

I. JENKINS.

Research Laboratories of the

General Electric Co., Ltd., Wembley.

July 3rd, 1947.

A NEW COMPANY has been formed to take over the business of E. G. Acheson, Ltd. The title of the new company is: Acheson Colloids, Ltd., 9, Gayfore Street, Westminster, S.W. 1.

The change-over is due to technical reason only; the same financial stability remains, and the management and staff are unchanged.

South Wales Laboratories of the British Iron and Steel Research Association

The Association's First Independent Laboratory for Co-operative Research

SKETTY Hall, Swansea, has been converted into a research laboratory. It is the first of the British Iron and Steel Research Association's efforts to set up independent laboratories for co-operative research in the various iron and steel producing centres. This laboratory was officially opened on July 3rd, 1947, by Mr. G. H. Latham, President of the Association, who received a gold key from the Mayor of Swansea for the purpose. Both the Mayor and Mr. Latham expressed their pleasure at the occasion, and the guests, about 60, proceeded on an inspection of the various sections.

The facilities provided in this laboratory are comprehensive and mainly intended for the work to be carried out in the investigation of problems concerned with steel coatings. Research work has been in progress for some time, and visitors were able to see demonstrations of the latest absorbtometric methods of analysis in the chemistry laboratory. The various heat-treatment furnaces were on view in the metallurgy section, and layer thickness measurement by an electrical gauge was demonstrated, as also was the conventional cupping test for measuring the adhesion of zinc coatings under deformation.

The section devoted to the work in South Wales of the Sheetmaking Division of B.I.S.R.A. was seen to be equipped with a quick immersion thermocouple, and apparatus developed for the rapid measurement of moisture in producer gas, which are both to be installed in a mobile laboratory, together with other equipment for this section's field tests on melting furnaces and works in the South Wales area.

In the electrochemistry department a rapid method of measuring the porosity of tinplate was demonstrated, where a sample is placed in a cell containing thiocyanate solution, and measurement is made of the strength of current required to eliminate the red colour which immediately shows on the sample where iron is exposed. This department is furnished with plating equipment powered through a rectifier of 16 volts 250 amps., capable of carrying out all types of plating.

In addition to the Talysurf profilometer, the physics section had on view the apparatus which is being used to deposit silver on plastic prints of roll surfaces, the object being to evaluate, with the aid of the Talysurf, the effect different roll surfaces have on sheet finish. This project is designed to discover further the effect sheet roughness has on the amount of tin required in coating.

Other sections were visited, and it was noted that each was well equipped for the work intended to be done. In a later issue it is hoped to give more detailed information regarding the facilities at this laboratory.

Following the inspection of the various sections of the laboratory, the visitors were entertained to lunch in Swansea's Civic Centre, and subsequently short speeches were made by the Mayor, Mr. G. H. Latham, Mr. Percy Morris, M.P., Sir Lewis Jones (Vice-President of the University College of Swansea), Capt. H. Leighton

Davies (Chairman of B.I.S.R.A. Coatings Committee) and Sir Charles Goodeve.

The Mayor paid tribute to Mr. Luther Phillip's work in the amazing transformation that had been effected at Sketty Hall, and expressed his confidence in the success of the laboratories, both to Swansea and to the industry at large.

Although so young among the 35 Research Associations, said Mr. Latham, the British Iron and Steel Research Association had already taken its place as an integral part of the industry, and was playing a major part in building up the output of steel which, no less than coal, was essential to the restoration of this country's economic well-being. The work of Research Associations could not be too closely defined, but they had been most successful when they had dealt with problems which lent themselves to co-operative effort and also when they had attempted to explore the theoretical background of essentially practical problems; in other words, when they have had both their heads in the clouds and their feet planted firmly on the ground.

It was part of the function of a Research Association to ensure rapid industrial application of scientific advances. The extent to which British inventions had been used to equip foreign industries was not always appreciated. Hot-blast and the cup-and-cone system in blast furnaces were cases in point, and above all the Bessemer and Thomas processes which put Germany on its feet as a large producer.

In emphasising the gratitude owed by the Association to the Swansea Corporation, Mr. Latham said that the programme of work for the Coatings Committee had continued without interruption by Mr. Phillips and his colleagues during the transfer of the work from the University College to the new laboratories, and while the laboratories were being installed. The early stages of this project were in some ways the most critical and the Association is greatly indebted to the efforts of Sir Lewis Jones, Secretary of the South Wales Siemens Steel Committee, and to the kindness of Principal Edwards of the University College for the facilities which were placed at the disposal of the staff during the period when the laboratories were not yet ready for occupation.

Alderman Percy Morris, M.P. pledged the Corporation to continued co-operation, paid tribute to the work that had been put into the conversion of the building, and said that B.I.S.R.A. were the best tenants the Corporation had ever had.

Sir Lewis Jones said that the steel industry, in producing its own scientists and carrying out its own researches was assured of the co-operation of the academic bodies, and he welcomed the fact that Sketty Hall was not to be a self-contained, watertight department. He looked forward to ever-increasing co-operation between the laboratories, the University College and the Technical College of Swansea which also had a part to play.

Capt. Leighton Davies mentioned that he was a

fairly substantial link between the old South Wales Siemens Steel Association and the present Coatings Committee of B.I.S.R.A. This was a red-letter day for him, who had been "in at the birth" of the research organisations of 20 years ago, since when no less than £59,000 had been spent on South Wales research. He had been associated with Luther Phillips during a large part of this period, and could pay him sincere and hearty tribute. He was glad to see that if the organisation had drifted from the University, it had not drifted far.

Sir Charles Goodeve expressed his sense of the appropriateness of Swansea as the venue for the opening of B.I.S.R.A.'s first independent laboratory for co-operative research. Co-operative research had had an early birth in Swansea, as Capt. Leighton Davies had pointed out. The acceleration of the rate of application

of scientific advance was an important task. He was particularly pleased that Sketty Hall was so near the University College, so that the close links would not be broken. At the same time it was valuable for the laboratory to be in the middle of this industrial district so that there would be ample opportunity for two-way traffic between works and laboratories. These laboratories were the property of the members of the Association, who would be most welcome to visit them and make the fullest possible use of them.

He, too, thanked the local authorities for their help, and concluded with a warning that the country at large must not look on scientific research, however valuable, as a panacea. We must work for success, which depends not on effort or science alone, but on the two combined.

Infra-Red Heating by Gas

MUCH publicity has been given to infra-red heating for processing, particularly as a result of some remarkably large reductions in the times of paint drying in comparison with those obtained by convection methods. A reduction of $1\frac{1}{2}$ hours to 3 minutes is quite common and must make those responsible for the finishing of bulk orders of components with paint or enamel, think seriously of the economics this method offers. Some of the possibilities of this form of heating were shown at the recent exhibition held at Gas Industry House, organised by the British Gas Council. At this exhibition were shown two types of medium temperature infra-red ovens, widely used in industry for paint drying: also on view were many components which had been treated by infra-red gas heating in the process of manufacture.

Infra-red heating is not new in itself. It is simply another name for an old process—the use of radiant energy for heat purposes. But it is only comparatively recently that it has been applied widely to industry where it is proving invaluable, resulting in the saving of millions of pounds in labour, space and overheads, and speeding up the production of everyday articles from cars to house fittings.

In this age of mass production and conveyor belt method of manufacture, infra-red heating by gas is proving to be the answer to the demand for a quicker process of applying localised heat. There are few industries which do not necessitate the use of metal which has to be protected by paint, taking time to dry.

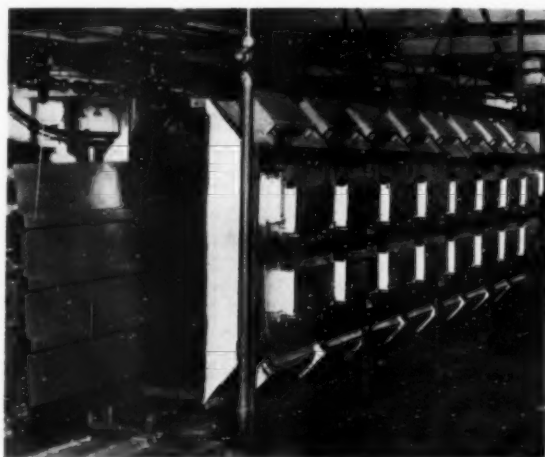
The principle is simple: Dull metal plates are heated by gas burners and the plates radiate heat. The temperature is controlled according to the object which is to be dried. The process is effected in two ways:—

- (a) By medium temperature black emitter panels; and
- (b) by high temperature incandescent sources.

The medium temperature range is from 450°–650° F., but a higher maximum can be obtained—to as much as 900° F. The high-temperature range varies between 1,100°–1,800° F. For almost all normal drying, however, and particularly metal finishing processes, temperatures up to 650° F. are adequate.

There are several systems of applying radiant heat, the two generally used being:—

Black Emitter Tunnels.—These consist of a row of non-bunsen type burners firing into a chamber, bounded on the one side by insulation and on the other by a mild-steel black panel. Even heat distribution is assured by



Drying paint on steel-house components at Steel Fabricators, Ltd., Cardiff, in an infra-red tunnel by Thomas Potterton (Heating Engineers), Ltd.

means of an inner sheet attached to the lower half of the radiating panel. The units are constructed in semi-cylindrical sections which are joined together to form a tunnel. A conveyor travelling through the tunnel carries the articles which are to be dried.

Black Emitter Flat Panels.—In this latest type of unit the same system of heating is applied, but the panels are flat. Being individually heated and controlled, these are easily adapted to the treatment of objects of all shapes and sizes. The units can be assembled in a variety of ways, according to the article to be dried. They can be built into circular section ovens through which objects, such as water-heater cases or bread bins, can be carried on a conveyor. For heating batches of articles they can be built into an oven of various shapes, sizes and designs; or into a sectioned tunnel of any required length. For treating flat sheets of metal they are used as walls or banks made up of panels placed vertically or at an angle.

A range of industrial processes in which application of infra-red appears to offer considerable advantages in speed will be given in an article specially prepared for this journal by Mr. J. B. Carne. This article deals with the development of infra-red heating by gas and its practise to-day, publication of which is expected to commence in our next issue.

MICROANALYSIS

CHEMICAL AND PHYSICAL METHODS

APPARATUS

METALLURGICAL APPLICATIONS

TECHNIQUE

WE have, at times, speculated about what appears to be the growing reluctance of people to commit their views to paper. In various places it has, from time to time, been deplored that the English man or woman is no longer a letter writer; and we must confess that in the past ten years our desire—or ability—to cope with our personal correspondence has steadily declined. In a recent editorial in *Analytical Chemistry*, the editor regrets that the response to his request for comments on a programme to publicise analytical chemistry "was more than disappointing—it was practically non-existent." In the present issue, elsewhere, we refer to a Report based on the replies to a questionnaire on the uses of microchemistry. Here, too, as the author shows in the original Report, only about one-third of the people who might be expected to have the strongest interest in the well-being of microchemistry have felt themselves impelled to indulge in a form of aid to its advancement which would involve merely the noting down, and despatching by post, the simple answers to a few simple questions. The appeal for information on this matter, which as a first step was addressed to members of the Microchemistry Group, solely as a matter of convenience, has now been extended to cover the wider field of any and every chemist who has an interest in microchemistry. It is to be hoped that however busy chemists may find themselves, and however tired they may be of all the forms of modern civilisation, if one may be permitted the double entendre, they will yet find time to contribute their share of information to this very desirable survey.

Polarographic Determination of Zinc in Aluminium Alloys

By W. Stross

An improved modification is given of the method previously published by the author for polarographic determination of zinc in aluminium alloys. An alternative technique, based on the same principle, but not requiring the use of a centrifuge, is also described, including a modification on the semi-micro to micro scale. The problem of, and the practical requirements for, a routine method of determining zinc in aluminium alloys is discussed.

IT can probably be said quite generally that polarographic methods find their most useful application for purposes of metallurgical production control in one of the two following cases:—

(a) For the determination of impurities in metals; the absence of large quantities, and large numbers, of alloying elements greatly facilitates the application of polarography, provided that the trace elements in question are generally reduced at less negative potentials on the dropping mercury cathode than the main constituent, or that special media can be found in which this is the case.

(b) In alloys, for the determination of such elements for which rapid, specific photometric methods are not available; the proviso of the preceding paragraph is, obviously, also important in this case for the ease of the applicability as only then can chemical separations be avoided completely or, at least, substantially reduced in comparison to other methods.

If equal time is required for preparing the final solutions, photometric methods will generally be preferable, as the act of measuring photometrically tends to be more rapid and simple, and the results are slightly more accurate.

It has often been claimed as an advantage of polarographic methods that they require very few chemical separations; it should, however, be borne in mind that the same applies to many, in some fields even to the majority, of modern photometric methods.

Gravimetric and electrolytic methods usually require considerably more time and sometimes more skill and experience, whilst the comparative merits of volumetric versus polarographic methods have to be considered individually in each case.

It was to be expected on those grounds that among the usual constituents of aluminium alloys zinc would offer particularly favourable opportunities for the application of polarography.

The composition of many of the practically important alloys, however, presented considerable difficulties. Whilst, obviously, a method applicable to even one single alloy only, *can* be useful, it is probably safe to say—at least for the alloys prevailing in this country—that only a method will be of general practical use by which the range from 0.02 to 15% of zinc can be covered in the presence of up to approximately 10% copper, or 1.5% iron, or 3% nickel, 10% magnesium, 13% silicon, 1% manganese, or similar amounts of more than one of these elements. Moderate quantities of titanium, bismuth, lead, cadmium, chromium, silver, zirconium and antimony must not interfere and, of course, the speed must be superior or at least equal to the classical¹ or the more recent² gravimetric and volumetric methods.

This practical aspect of the problem does not seem to have been generally understood. Thus, in one of the latest major polarographic publications on the subject³ two methods are given, a rapid and a long-winded one, the latter stated expressly to be too slow for routine purposes; the rapid method, however, is stated to be applicable only where less nickel than zinc is present. With regard to the conditions encountered in practice—at least in this country—the conclusion seems inevitable that the practical problem has not been solved.

The same remarks apply to several methods^{4,5} stated to be applicable to certain types of alloys only, although they may, of course, be useful for the special purpose.

The method published several years ago from these laboratories⁶ satisfies the above requirements and has been applied successfully in routine on a large scale ever since. The subject is reopened here because some improvements were lately introduced which are thought to justify a further communication, although the principle remains unchanged.

Principle of method.—The procedure is based upon the following general considerations:—Aluminium is reduced at a more negative potential than zinc so that its presence will not interfere. Both elements are soluble in sodium hydroxide solution whilst most of the other alloying elements, particularly those from which interference is to be expected, are insoluble. Zinc gives a not ideal, but reasonably good wave in sodium hydroxide solution, even up to considerable alkalinity. This will be discussed more fully below.

Various authors, following this obvious line of thought, have simply attempted to attack the alloy with sodium hydroxide solution (or to dissolve the alloy in acid and to pour into an excess of caustic soda) and to determine the zinc polarographically directly in the liquid thus obtained. These attempts are, however, doomed to failure—special cases of composition excepted—due to

two further facts: (a) A very substantial part of the zinc, as has been recognised by several authors^{4, 5, 7} does not go into solution by simple caustic attack; (b) when acid solutions of aluminium alloys are made alkaline with sodium hydroxide, a co-precipitation of zinc with the hydroxides of iron, copper, magnesium and other elements occurs.

An attack of the alloy by hydrochloric or sulphuric acid has also been proposed, with a view to separating the zinc and other non-interfering elements from the bulk of the copper, nickel and silicon. Copper as well as silicon, however, tenaciously retains some zinc also under these conditions although the loss is likely to be smaller than with caustic attack only. In addition, iron and other interfering elements will also be dissolved, at least partly.

The method developed by the author⁶ whilst making use of the above favourable facts, reduced the losses mentioned to negligible proportions in the following way:—

By attacking the alloy with sodium hydroxide solution, followed by centrifuging, decanting and washing of the precipitate, at least 70–90% of the total zinc present is removed at once and not further exposed to losses by co-precipitation. The residue is dissolved in acid and to this solution is added a large excess of caustic under conditions so chosen that the loss of zinc by co-precipitation is kept low. After centrifuging again, the supernatant liquid contains the bulk of the zinc left behind with the copper fraction during the first attack.

This second alkaline fraction is united with the first one. After washing, the precipitate is redissolved in acid, reprecipitated by excess of sodium hydroxide and, after centrifuging, the supernatant liquid is again united with the two other alkaline fractions.

If the loss by co-precipitation, after the first acid addition, were as high as 20% of the 20 to 30% of the total zinc remaining undissolved by the first caustic attack, this would only mean a loss of 6% of the total zinc during the first operation; if the second precipitation again leaves behind 20% of this, the total loss would be about 1%. This is without significance in the range of say less than 0.25% zinc, and even in this range the above assumptions are exaggerated. The losses are certainly *very* much smaller in the higher ranges of zinc contents where the proportion of zinc to the other constituents is much more favourable.

The use of the centrifuge was not merely a matter of expediency and of saving of filter paper⁸; one of the main purposes was to keep the volume of the acid solution lower than can be achieved—at least without subsequent evaporation—when a precipitate is dissolved from a filter.

To keep this volume small is important as it had been found that the loss by co-precipitation is considerably smaller under these conditions.*

Whilst the use of the centrifuge is still considered to be the most useful procedure for routine purposes, a modified technique was also developed which does not require the use of this instrument.

Both procedures are given in detail below.

1 (a) Analysis of Aluminium and its Alloys, The British Aluminium Co. Ltd., 1941. Publication No. 399, pages 36 and 69; and

(b) Chemical Analysis of Aluminium, Aluminum Company of America, 1941.

2 J. H. Bartram and P. J. C. Kent, *Metallurgia*, 1946, 33, 179.

3 I. M. Kolthoff and G. Matsuyama, *Ind. and Eng. Chem., Anal. Ed.*, 1945, 17, 615.

4 (a) G. Geuer, *Aluminium* (Germany), 1943, 25, 28.

(b) K. Steinhauser, *ibid.*, 1942, 24, 173.

(c) R. Bauer and J. Eisen, *Metall. und Erz*, 1942, 100.

(d) W. Boehm, *Z. anal. Chem.*, 71, 243.

(e) A. Cohen, *Heiv. Chim. Acta*, 1942, 25, 325.

(f) F. Jablonski and H. Moritz, *Aluminium*, 1943, 25, 291.

(g) "Aslib"-microfilms of the war-issues of "Aluminium" are obtainable in this country.

5 Spectrochemical and Polarographic Analysis of Aluminium and its Alloys, British Aluminium Company, Publication No. 401, 1943, page 74.

6 W. Strom, *Light Metals*, 1944, 7, 325.

* These experiments have been utilised by J. H. Bartram and P. J. C. Kent⁹ when developing their gravimetric procedure of zinc determination with the use of quinaldine acid, and fuller particulars can be found in their paper.

7 G. H. Osborn, *Journ. Soc. Chem. Ind.*, 1943, 62, 58.

8 W. Strom, *Industrial Chemist*, September, 1943.

1. Procedure with the Use of the Centrifuge

"40%" sodium hydroxide solution (40 g. of the solid plus 100ml. of water).

Diluted sulphuric acid, 1 : 1.

Potassium chlorate, saturated aqueous solution.

Gelatine, 0.25% solution, kept sterile by adding a pea size crystal of thymol.

Procedure.—Place a 500 mg. sample into a centrifuge tube of convenient size ("heavy-weight" test tubes, $6 \times \frac{3}{4}$ in. are very suitable). Add 2 ml. of water and 1 ml. of the sodium hydroxide solution. When the violent reaction subsides—cooling is nearly always required to prevent overflowing—add another 2.5 ml. of the caustic solution. With very finely divided samples, e.g., powders, it is necessary to add the caustic in three portions, e.g., 0.5, 0.5 and 2.5 ml. If wider tubes are used, e.g., 5×1 in. (of which only a smaller number can be carried by certain centrifuges) no water is required and the caustic can be added in one portion, some cooling likewise being required.

Complete the reaction by washing down the walls with about 2 ml. of hot water and by immersing in boiling water. Centrifuge and decant into a 25 ml. measuring vessel ("heavy-weight" test tubes, $7 \times \frac{3}{4}$ in., accurately calibrated at 25 ml. are very suitable). Wash the residue by adding 2 to 3 ml. hot water, shaking up the precipitate, centrifuging and decanting into the same 25 ml. measuring vessel. Repeat the washing once.

Add 0.5 ml. of the sulphuric acid 1 : 1 and 1 ml. of the potassium chlorate solution, stir and wait until the copper, etc., dissolves. Accelerate this, if necessary, by gentle warming.

Add with vigorous shaking 2.5 ml. of the 40% sodium hydroxide solution, centrifuge and decant into the measuring vessel. The centrifugate at this stage shows a strong blue colour if the alloy contains much copper. Wash the residue by centrifuging with 2 ml. hot water and decant into the measuring vessel.

Dissolve the residue again in 0.5 ml. of the acid, a further 0.5 ml. chlorate solution being sometimes required.

Precipitate, centrifuge, decant and wash as before.

Add 0.4 ml. gelatine solution, make up to the mark, add $\frac{1}{2}$ of a Whatman accelerator, shake well and filter through an 11 cm. Whatman 542 filter, using dry apparatus or rejecting an adequate portion of the filtrate. Test tubes $6 \times \frac{3}{4}$ in. are very suitable for collecting the filtrate.

Calibrate by treating a standard alloy in the same way.

This procedure differs from that published before by the author⁶ mainly by the use of potassium chlorate instead of hydrogen peroxide. This has the advantage that the excess of the oxidant need not be destroyed as the chlorate is polarographically inactive. This results in a considerable saving of time.

Strong and prolonged heating with the chlorate should be avoided, otherwise peculiar distortions of the zinc wave may occasionally occur. In such cases, after reaching the level it should reach according to the zinc content, the graph falls to about half this height. This produces the appearance of a maximum of the rounded type; the highest point of the wave is, however, not higher than expected (it would be higher in the case of a true maximum).*

* These curves are rather similar to the distorted nickel wave shown as curve 2 in Fig. 1 of the paper by Kolthoff and Matsuyama.⁸

This rather rare phenomenon is peculiar only to certain melts of alloys of various types and it has so far not been possible to connect it with any particular chemical composition, as the majority of samples of apparently identical composition do not show it, whilst it is reproducible on the given specimen.

If no, or only gentle heating is applied, the phenomenon has been seen only once among the many samples tested. In this case normal results were obtained using hydrogen peroxide, with the use of which this strange phenomenon has never been observed so far, in the course of many thousands of determinations.

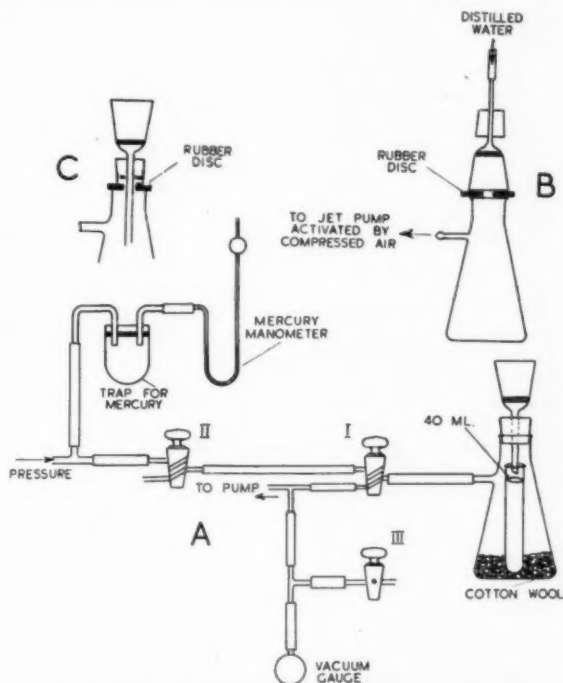


Fig. 1. Sketch A illustrates the experimental arrangement for the technique using sintered glass funnels. Sketch B and C explain the cleaning, as described in note 11.

2. Procedure Without Centrifuge

Reagents and apparatus required:—

Sodium hydroxide and potassium chlorate solutions as before.

Diluted sulphuric acid, 1 : 3 (25% v/v.).

Diluted sulphuric acid 1 : 7, i.e., the above solution diluted with an equal volume of water.

Sintered glass funnels (Baird and Tatlock, M 141, H 2, diameter of disc 30 mm., porosity 2).

Boiling tubes 6×1 in., with a calibration mark at approximately 7 ml. The "heavy-weight" type is very suitable.

Similar tubes, exactly calibrated at 40 ml.

A source of pressure, e.g., a hydrogen or nitrogen cylinder with pressure reducing valve; a pressure of 1 to 2 in. of mercury is adequate.

The sketch A of Figure 1, which is self-explanatory, illustrates the simple experimental arrangement, enabling pressure and suction to be applied in rapid alternation upon the lower surface of the sinter funnel (see remark 8, below).

Procedure.—Prepare a small paper pulp pad on the sinter funnel by stirring one Whatman accelerator with a little water in it until disintegrated, and sucking off. Attack a 500 mg. sample in a boiling tube, marked at 7 ml., with 5 ml. of the sodium hydroxide solution, cool slightly, wash down the walls, then complete the reaction by immersing in boiling water, or by boiling over a Bunsen burner.

Cool, dilute to 7 ml., pour into the funnel (which is connected to one of the tubes calibrated at 40 ml., as shown in the sketch). Suck off by first turning the two-way cocks I and II into the positions as shown in the drawing, and, after this, closing stopcock III which should be open until the liquid is actually in the funnel.

Wash the tube and the funnel with about 7 ml. hot water in about 5 portions (a 10 ml. straight pipette with fast outflow is advantageous). Use a glass rod if necessary, to detach adhering particles from the wall of the tube. Place the glass rod into the funnel.

Release the vacuum by opening stopcock III and apply pressure by turning the two-way cocks I and II through 180 degrees.

Pipette 1 ml. each of the potassium chlorate and of the dilute sulphuric acid (1 : 3) into the boiling tube, mix and pour into the funnel, rotating the tube, so as to dissolve any metal particles adhering to the wall (which should normally not be the case). Drain well but do not wash the tube. Stir the content of the funnel with the glass rod, breaking up the pulp pad. In a few seconds the metals insoluble in sodium hydroxide are dissolved. Pipette 4 ml. of the sodium hydroxide solution into the funnel and mix well with the glass rod, which then remains in the funnel during the rest of the operations.

Turn the two-way cock II through 180 degrees, thus releasing the pressure and apply suction by turning the two-way cock I likewise through 180 degrees, then closing stopcock III. Wash the pulp pad with about 7 ml. hot water from a pipette, stirring up the pulp pad to avoid channel formation.

Reapply pressure (i.e., release vacuum by opening stopcock III, then turn cocks I and II through 180 degrees), pipette 2 ml. of the 1 : 7 dilute sulphuric acid

on to the pulp pad, stir: when the acid soluble hydroxides are dissolved, add 4 ml. of the hydroxide solution, stir, and again apply suction by turning first cock II, then cock I through 180 degrees, eventually closing stopcock III. Wash with as much hot water as the calibration mark on the tube (40 ml.) will allow.

Disconnect and add 0.65 ml. of the gelatine solution to the content of the tube, make up to the mark, add half of a Whatman accelerator, shake to disintegrate the accelerator and to mix; finally filter through a 542 Whatman filter, using dry apparatus or rejecting an adequate portion of the filtrate.

3. Procedure on a Semi-micro and Micro Scale

By using a micro sinter funnel, Baird and Tatlock, M232, H3, diameter 10 mm. (the tall form being more advantageous) all the above quantities can be reduced to $\frac{1}{10}$ so that a weighing of 50 mg. covers the range down to zinc contents of approximately 0.02%. With higher contents very much smaller samples can be taken and a sample of 10 mg. still allows contents of 0.1% to be determined with reasonable accuracy, particularly if a higher sensitivity of the polarograph is employed than that normally used for the techniques described under 1 and 2 (see below, remark 6).

With still higher zinc contents, the sample can be reduced accordingly so that (even without further reduction of the quantity of reagents which should also be quite feasible) 1% of zinc could be determined on a 1 mg. sample.

The accuracy and precision of either technique is the same as that characterised in the author's first paper^a about the subject and no further data are therefore given; more attention was paid this time to the accuracy obtained on alloys with high magnesium content (up to 10%). A suitable D.T.D.300 alloy was therefore analysed repeatedly polarographically and sent for a check to two independent laboratories.* The polarographic result was constantly 0.18%, the checks were 0.18 and 0.19% respectively.

(To be continued)

* The author wishes to thank Mr. F. B. Crossley (Messrs. Enfield Rolling Mills Ltd.) and Mr. W. H. Hadley (Messrs. T. J. Priestman Ltd.) for their co-operation in carrying out these tests; they used the mercuric thiocyanate method with a gravimetric and volumetric finish, respectively.

The Uses of Microchemistry

FOLLOWING on an earlier report prepared under the auspices of the Microchemistry Group, on the teaching of microchemistry in Great Britain¹, a new Report, dealing with the applications of microchemistry for industrial and research purposes in this country has also been prepared, and has recently been published². In this latter Report the ways in which microchemistry is applied both to routine problems of analysis and to research have been collated, tabulated and analysed. As a *point d'appui* the data were first sought from the members of the Microchemistry Group only.

A considerable amount of interesting information is presented, and it has been concluded that an investigation over a wider range of chemists would be profitable.

The author of the Report, therefore, invites chemists throughout the country, whether users of microchemistry or not, to supply any information which would give a fuller picture of the present uses of micro methods, following along the lines of the Report. The main headings under which information is sought are: (1) The general class of the laboratory; (2) the general branches in which microchemical methods find application, if used; (3) whether the technique is in routine or in occasional use; (4) the average size of sample to which it is applied; (5) the advantages or disadvantages claimed for the technique; and (6) any other points of interest.

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¹ Cecil L. Wilson, *Nature*, 1945, **156**, 588.

² Cecil L. Wilson, *Chem. and Ind.*, 1947, 353.

Brinell Hardness of Grey Cast Iron and Its Relation to Other Properties

By J. T. Mackenzie

DURING the last few years there has been an increasing tendency to introduce a maximum value for Brinell hardness in specifications for grey cast iron which called for a minimum tensile strength. This was a simple and reasonable method of obtaining the desired machinability without using the dubious alternative of putting a maximum on the strength, since it was hardly conceivable that a casting could be too strong if the unnecessary strength was obtained without sacrifice of the other desirable properties. In order to have some reliable criteria for setting up such specifications a study was made of available data and presented in a report to Committee A.3 at the recent annual meeting of the Society of Testing Materials.

A great deal of the data dealt with was obtained from experimental heats but much more was obtained from actual operations. Most of the experimental heats were average results from duplicate test bars, and the operating results usually included from 10 to 50 readings from as many bars of each grade of iron being made. A total of 1553 sets were submitted showing both tensile strength and Brinell hardness. There were 145 0.875 in. bars; 988 1.2 in. bars; 171 2.0 in. bars; 46 3 to 10 in. bars and remainder were from bars cut from the desired sections of actual castings.

The data obtained were plotted and then analysed statistically and values obtained for the tensile strength according to the parabola $TS=1.82$ (B.H.N.)^{1.85}, calculated for each 0.1 mm. of diameter from 3.2 to 5.8. In Table I is given a summary of the Brinell-tensile data showing the standard deviation of the Brinell hardness number (B.H.N.), both in numbers and percentage for each tensile class together with the actual

TABLE I.—SUMMARY OF BRINELL-TENSILE DATA

Tensile Class	No.	Average Tensile Stress 1,000 lbs. sq. in.	Average Brinell Hardness Number	Standard Deviation B.H.N.	Standard Deviation % Aver. B.H.N.
10	5	13.1	111	21	19
15	12	17.7	153	11	7
20	29	22.6	166	10	6
25	65	27.9	187	16	8
30	185	33.1	204	12	6
35	383	37.4	216	16	7
40	297	42.6	230	19	8
45	172	47.0	243	27	10
50	179	52.3	255	33	13
55	108	56.9	262	35	13
60	36	62.3	285	33	12
65	41	67.3	286	32	11
70	22	72.4	302	25	8
75	10	76.9	294	29	10
80	9	82.5	335	19	6

average of the Brinell hardness and tensile strength. There was no *a priori* reason to assume that the Brinell-tensile relation would change with section size, but the sizes were plotted separately to make sure. No difference was found except in the case of the 2 in. bars, but this was considered not to be due to section effect, but to a large number of bars verging on (if not actually in) the martensitic condition and usually high in manganese and/or molybdenum.

A study was also made of the effect of the elements nickel, chromium, copper, molybdenum, manganese and phosphorus. Irons with over 2% copper, 3% nickel and 1% phosphorus were invariably on the low side unless well balanced or heavily inoculated. Inoculated irons, in general, were fairly close to the average of all groups or showed a strong tendency towards the upper side of the diagram. Some hundred heats of white irons were examined and all fell in the lower part of the diagram.

Investigations were also made of the available data for other correlations with the Brinell hardness number of grey cast iron especially those applying to the transverse test. In the bars submitted for examination, there were

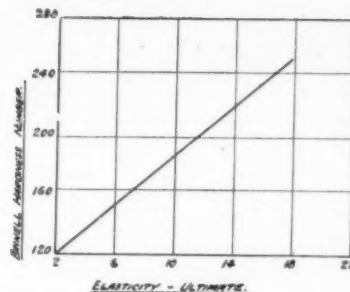


Fig. 1.—Relationship between hardness and stiffness.

1023 with accompanying transverse data, as well as information on tensile and Brinell properties. The bars were made up in sizes varying from 0.875 to 3 in., and since the tensile-Brinell relation was satisfactorily established it was only necessary to determine the ratio of transverse strength to tensile strength to obtain the transverse-Brinell relationship.

TABLE II.—RELATION OF IMPACT PROPERTIES TO VARIOUS TENSILE/B.H.N. RATIOS.

Drop Test	Equation	Constants ^a	Standard Error	Correlation Coefficient
	m.	b.		
Tens/BHN	0.105	6.7	12.4	0.929
Tens ² /BHN	0.112	4.4	11.9	0.943
Tens ³ /BHN ²	0.046	6.0	12.2	0.949
Pendulum Impact				
Tens/BHN	0.205	4.6	24.17	0.847
Tens ² /BHN	0.629	19.7	19.15	0.827
Tens ³ /BHN	0.265	27.7	20.17	0.877

Drop Test—1.20 in. diam., 6 in. span, $\frac{1}{2}$ in. increment, 25 lb. hammer.
Pendulum—Charpy type, 1.2 in. diam., 18 in. span.
Equation— $Tens/BHN = m(Drop \text{ or } Pendulum) + b$.

Since few data on deflection were available, except at the breaking point, impact tests furnished a reasonably good approximation for the relationship of Brinell hardness and stiffness. Fig. 1 shows a very good correlation to be obtained with a small error even when the data used included that from two irons, one of which was austenitic and the other martensitic. If these irons were omitted a much better agreement would be obtained.

The simple ratio tensile/B.H.N. was used on impact data with fairly good results, but it appears that some

From *The Foundry*, 1946, Vol. 74, No. 10, pp. 88-93, 191 and 194).

higher power of the tensile would give better results. Two more ratios were used, tensile $\frac{3}{2}$ B.H.N. and tensile $\frac{3}{2}$ B.H.N.² The relation of impact properties to those various ratios is given in Table II and shows fairly good correlation with both the drop test and the pendulum test, although the drop test correlates better than

the pendulum since it is nearer to the triangular resilience than the pendulum Charts for tensile $\frac{3}{2}$ B.H.N.² showed that this was the best relation when the same metal was being tested. In general, however, for a given tensile strength more toughness can be expected from low hardness values than from high hardness values.

Graphite in Cold-Rolled Subcritically Annealed Hypoeutectoid Steels

By M. A. Hughes and J. G. Cutton

THE graphitisation of steels containing 1% carbon or greater has been well recognised by those who anneal and process steel of this composition, and adequate precautions have to be taken to prevent the formation of graphite when such steels are annealed. A study has been made to determine the effect of temperature, residual alloys, variations in per cent. cold reduction, mode of oxidation, full annealing prior to cold reduction and carbon content, on the susceptibility of hypoeutectoid steels to graphitisation when cold-rolled and annealed at subcritical temperatures. In addition to the study of those factors which promote graphitisation, the investigation was extended to determine the solution rate of graphite once it had been formed in the cold-rolled annealed strip.

In Table I are given the compositions of the steels used for the various experiments. Hot-rolled strip samples, suitable for cold-rolling, were obtained from each heat and cold-rolling was carried out by passing strip samples between rolls of a small mill. After cold reduction, samples were annealed and, in order to minimise surface decarburisation during annealing, all samples were wrapped in "waster sheets" and sealed in an airtight container. The solution rate of graphite was determined by austenitising

small graphitised samples in a covered lead bath for several intervals of time and quenching in brine. Samples were then polished and the percentage of graphite estimated microscopically.

The effect of time and temperature of annealing on the graphitisation was determined on steels A, B and C. After various cold-reductions and annealings, the 0.039 in. cold-rolled strip was given a final annealing for 1, 3 and 5 days at temperatures of 595°, 620°, 650°, 675° and 705° C. In addition one set of samples from each steel was annealed for 7 days at 705° C. Steel A was found to contain graphite after 3 and 5 days at temperatures of 620°, 650° and 675° C., and after 7 days at 705° C. The most favourable temperatures were between 620° and 675° C., and any variation from this range of temperature decreased the rate of graphite formation. Steel C, processed similar to steel A but containing higher residual alloys, and steel B, given a single reduction prior to final annealing, failed to graphitise when subjected to the same final annealing as steel A. Annealing times longer than those generally used in commercial annealing were required to graphitise the cold-rolled strip of steel A.

The effect of residual alloys, copper, chromium and nickel, and per cent. cold reduction on graphitisation were investigated simultaneously by adding copper to one ingot and copper,

chromium and nickel to a second ingot of a heat of fine grained carbon steel. These two steels E and F were then compared with steel D. After a cold-rolling and annealing procedure it was found that cold-rolled annealed strip with increasing amounts of residual alloys was definitely less susceptible to graphitisation. Chromium was found to stabilise the carbides, while copper appeared to have no effect upon the stability of the carbides. When cold-rolled strip samples were subjected to two cold-reductions, totalling 50% reduction, and two subcritical annealings totalling 144 hours at 650° C., it was observed that first reductions of 10, 20 and 30 per cent. produced more graphite than 0, 40 and 50% first reductions.

A hot-rolled strip sample from Steel D was heated to 870° C. and furnace-cooled to 425° C. at the rate of 0.5° C. per minute. The fully annealed sample was then subjected to the same cold rolling and annealing procedure as that used in studying the effect of cold reductions. The effect of this full annealing prior to cold reduction and subcritical annealing was found to greatly enhance graphitisation. Hot-rolled strip of Steel G, made by a coarse grain deoxidation practice did not graphitise when subjected to cold rolling and annealing procedures which readily produced graphite in similar steels made to a fine grain deoxidation practice. It would appear, therefore, that aluminium or alumina or both were important factors in promoting subcritical graphitisation.

Hot-rolled strip samples from fine grained steels I, H and F, having carbon contents of 0.08, 0.43 and 0.67% carbon and two commercial heats of silico-manganese, J and K, were experimented with to determine the effect of carbon on graphitisation. It was found that such steels were graphitised when cold-rolled and subcritically annealed.

To determine the solution rate of graphite in cold-rolled annealed strip at normal heat-treating temperatures, small samples from Steels D, I and J were heated in a lead bath at 900° C. for various lengths of time and brine quenched. The samples were then polished and the percentage of graphite remaining after each interval of time was estimated metallographically, when it was found that the solution rate of graphite in cold-rolled annealed strip at heat-treating temperatures was a function of the temperature, the graphite particle size, and the amount of graphite present.

From American Society for Metals, 1945, Preprint 13, pp. 1-25.

TABLE I.—COMPOSITION OF STEELS USED.

Mark	Deoxidation Practice	Mould Additions	Composition.								
			C	Mn	P	S	Si	Cu	Cr	Ni	Al*
A	Fine Grain	None	0.65	0.54	0.011	0.027	0.18	0.01	0.03	0.02	0.020
B	"	"	0.67	0.47	0.012	0.025	0.18	0.02	0.02	0.01	0.019
C	"	"	0.60	0.44	0.008	0.022	0.19	0.09	0.06	0.07	0.027
D	"	"	0.63	0.53	0.024	0.032	0.15	0.01	0.02	0.01	0.019
E	"	Cu	0.64	0.54	0.023	0.034	0.15	0.18	0.03	0.02	0.021
F	"	Cu, Cr, Ni	0.67	0.53	0.023	0.030	0.15	0.14	0.09	0.09	0.020
G	Coarse Grain	None	0.58	0.70	0.012	0.032	0.14	0.01	0.01	0.01	0.002
H	Fine Grain	"	0.43	0.52	0.012	0.026	0.19	0.01	0.02	0.01	0.021
I	"	"	0.08	0.32	0.008	0.020	0.002	0.06	0.01	0.01	0.063
J	"	"	0.63	0.81	0.013	0.020	1.85	—	—	—	0.059
K	"	"	0.59	0.85	0.008	0.017	2.03	—	0.34	—	0.045

* Metallic Aluminium (Does not include Aluminium as Al_2O_3).

Effect of Alloys in Steel on Resistance to Tempering

By W. Crafts and J. L. Lamont

AN empirical method has been developed for calculating the hardness and tensile strength of quenched and tempered engineering alloy steels. In developing the method, simple and complex steels were tested over a range from 0.08 to 0.65% carbon and up to 2.68% manganese, 2.18% silicon, 3.5% chromium, 4.94% nickel and 1.06% molybdenum. The experimental steels were made as small induction furnace heats, and the accuracy of the method was finally checked on a variety of carbon, low-alloy and high-alloy types of heat treating-steels produced under commercial conditions. The method was based on a study of tempered Jominy bars and its validity was tested by correlation with the centre hardness and tensile strength of oil-quenched and tempered bars from $\frac{1}{2}$ to 4 in. in diameter.

The method of calculation was derived from the differences in Rockwell C. hardness between as-quenched and quenched and tempered Jominy specimens. Prenormalised Jominy hardenability specimens quenched from a normal temperature for austenitisation were used to obtain a range of as-quenched Rockwell C. hardness. These specimens were then tempered for 2 hours at 205°, 315° and 425° C. Hardness determinations were made and the same specimens were re-tempered at 540°, 595° and 650° C. respectively. Hardness values at six points (2/16, 4/16, 8/16, 16/16, 24/16 and 32/16 in. from the water quenched end of the Jominy specimen) were used for calculating the tempering factors).

The pattern and factors for the calculation were developed by graphically comparing the initial as-quenched Rockwell C. Jominy hardness with the hardness obtained after tempering the specimens at different temperatures. At first, similar simple steels with graduated carbon contents were studied, the basic pattern was outlined, and rough factors for the effects of carbon and temperature were estimated. Manganese and silicon steels were then processed, using the rough carbon and temperature factors. Using these approximate manganese and

silicon factors, the effects of carbon and tempering temperature were then redetermined. Other simple alloy steels and finally complex alloy steels were introduced with recycling of the data until no significant changes were indicated.

Results obtained show that the calculation is accurate within about 5 Rockwell C. hardness or 6.7 tons per sq. in. tensile strength, and is suitable as a guide in the prediction of hardness and strength for relative evaluation and selection of alloy steels. Tempered hardness was found to be primarily dependent on as-quenched hardness, both on account of the effect of initial hardness itself and because alloys exert their full resistance to softening only in steels hardened above a critical level. With increasing tempering temperature, the degree of softening of hardened steel

depends on carbon, except for the effect of nickel and except as softening is arrested in characteristic temperature ranges by the secondary hardening effect of silicon, manganese, chromium, molybdenum and vanadium. Secondary hardening appears to be associated with the transition of the alloying element from ferrite to carbide.

The amounts of alloy that retard softening by one Rockwell C. unit after 2 hours at the higher tempering temperatures in a 0.3% carbon steel are: 0.4% manganese, 0.22% silicon, 0.19% chromium, 0.77% nickel, 0.06% molybdenum, and 0.03% vanadium. The relative effects of alloys in resisting softening are materially different from their relative effects on hardenability, so after the same heat treatment steels of equivalent hardenability but different composition may vary considerably in tempered hardness and tensile strength. The ratio of softening resistance to hardening power of alloying elements increases in the following order: boron, carbon, manganese, nickel, chromium, molybdenum, silicon and vanadium.

The Development of the Electric Steel Furnace During the World War, 1939-45

By Erik Sunström

A STUDY of available statistics pertaining to steelmaking reveals a considerable increase in the production of electric furnace steel. This increase was especially rapid before and during the second world war and took place in most steel-producing countries. In England and the U.S.A. electric steel comprised 5-7% of the total steel tonnage produced during the later years of the war period. In Sweden, the corresponding figure was about 30%. Together with the increase in electric steel furnace capacity and the expanding manufacture of electric steel ingots and castings, followed also numerous interesting new developments, not only in the metallurgical field, but also along electrical and mechanical lines. Electric furnace refractory materials were also greatly improved. The present paper discusses such improvements and compares Swedish and foreign, especially American, electric furnace practice.

The design of the electric arc furnace is discussed in detail. While nominal furnace capacity in Sweden approxi-

mates an individual max. of 25 tons. England has installations rated at about 40 tons and the U.S.A. and Germany have both installed arc furnaces of 75 tons nominal capacity.

American magnesite furnace bottoms for which dead-burned dolomite is used as a fettling material, show considerably longer life than Swedish tar-mixed burned dolomite bottoms. The American method of using steel-clad magnesite or chrome-magnesite brick for furnace walls is compared with the Swedish practice of ramming the furnace walls with the same tar-dolomite mixture which is used for the bottoms.

A comparison between different types of electrodes indicates that the area of a self-baking Söderberg-electrode is about 2.5 times the area of the regular graphite electrode. The advantage of basket-charging, at least for furnaces up to 30 tons capacity, is emphasised.

Factors affecting the manufacture of basic electric steel and the metallurgy of the basic electric process are considered, with particular stress laid

From *Metal Technology*, 1946, Vol. 13, No. 6, and *A.I.M.M.E. Tech. Public.* 2036, pp. 1-21.

From *Jernk. Annal.*, 1946, 120, 477-552.

on the production of high quality steels. In the U.S.A., in order to shorten the refining period, several plants have resorted to a preliminary deoxidation, or reboil of the bath, at the end of the oxidation period.

Several duplex-processes and other "rapid" processes are mentioned. In addition to the Perrin process, an American method of washing refined basic electric steel with its own slag by reladling the contents of the tapping

ladle into a second pouring ladle is described. Furthermore, a method is made public, which permits the making of stainless steel by mixing in a ladle a highly alloyed heat with a low carbon virgin metal heat.

The design of the high-frequency furnace, the lining problem of this furnace and some other aspects with regard to this furnace are given due attention. Finally, some economic viewpoints on electric furnace manufacture are given.

Sodium Hydride Descaling

By E. L. Cady

SODIUM hydride descaling of metals is a new process, developed in the last four years, in which the metal is held in an open tank or vat filled with a mixture of caustic soda and from 1.5 to 2.0% of sodium hydride, at about $370^{\circ}\text{C.} \pm 5^{\circ}\text{C.}$ When the metal to be descaled is immersed in this mixture, the oxygen hungry sodium hydride reduces the oxides in the scale and thus turns the hard and adherent scale into a loose and flaky or powdery

mass. When the metal with its temperature raised to 370°C. by the bath is quenched in cold water, the water in contact with the metal at this temperature forms steam which blast off the scale. Subsequent treatment may include a dip in dilute acid (usually 10% sulphuric acid) to neutralise any caustic soda remaining on the metal, and nitric or other acid dips for bleaching or passivating effects.

The holding temperature of the process is important. If it exceeds

370°C. there is a costly loss of hydride, and if it gets too low then the coating of caustic soda, which solidifies or freezes about the cold metal when it is first immersed in the bath will be slow to liquefy, and the entire bath may be cooled below its correct reaction temperature, with the result that the process will be slowed down in production capacity. The temperature must, therefore, be controlled within narrow limits.

In operation, the sodium hydride reaches, or can be made to reach all surfaces to which liquid can flow, and descaling is uniform. So long as the metal remains in the bath long enough to reduce the scale, usually 10 or 12 minutes, it can remain there as much longer as desired, as there is no danger whatever of over-pickling. One result of this is to modify the need for exact timing of scale removing operation cycles, and another result is that complex parts having small recesses or severe undercuts can have their scale removed with much greater ease, and so eliminate one of the common troubles of pickling, namely the over-pickling of exposed surfaces while getting the scale off from the less exposed ones.

From *Materials and Methods*, 1946, 23, pp. 1278-1283.

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In the process, pitting troubles are reduced to the vanishing point as the sodium hydride itself will cause no pitting whatever, and it will not set up any of the common causes of pitting for the acids in subsequent steps to work upon. There is also no hydrogen embrittlement of steel and no need to heat the steel for a prolonged period to eliminate hydrogen from it.

Rates of High-Temperature Oxidation of Magnesium and Magnesium Alloys

By T. E. Leontis and F. N. Rhines

THE oxide scale that forms upon magnesium at elevated temperatures is non-protective in the sense that the rate of oxidation is constant and thus does not decrease with the growth of the scale as it does with other common metals. Many investigations have been devoted to the nature and rates of "protective" oxidation as exemplified by the case of copper and iron, wherein the rate is characteristically parabolic. There exists no comprehensive survey of the high-temperature oxidation of magnesium (or of any other metal that exhibits linear oxidation) over a broad range of temperature, under a variety of atmospheric conditions and covering a large group of alloys. An investigation was therefore carried out to provide such a survey with the object of gaining a fuller understanding of linear oxidation, especially as applied to magnesium. The experimental studies undertaken were of two kinds: (1) measurement of the rate of oxidation as influenced by the several variables mentioned and (2) supplementary experiments designed primarily to discover what structural changes accompanied the oxidation process.

The extent of oxidation was followed by a continuous measurement of the weight increase of a sample using a specially designed equipment. Recast sublimed magnesium containing 99.95% magnesium with not more than 0.01% each of aluminium, cadmium, copper, manganese, silicon and zinc and not more than 0.001% each of iron, nickel and lead was used throughout for preparing the various alloys. Alloys were prepared by melting 200 grams of this magnesium in a graphite crucible under a chloride flux, adding the purest grades of the alloying elements and casting in a heated (500° C.) graphite mould. The

Besides stainless and alloy steels, a wide range of metals can be treated by the sodium hydride process, including alloys of chromium, copper, nickel, tungsten, cobalt and also plain carbon steels. The process is also especially useful with combined or clad metals consisting of two alloys which if pickled would require entirely different exposure times to the pickling acid.

TABLE I.—COMPOSITION OF ALLOYS STUDIED.

Alloy No.	Wt. % Br. Chemical Analysis.	Wt. % Br. Spectrographic Analysis.*
1	1.78 Al	
2	3.81 Al	(0.003 Pb.)
3	7.23 Al	(0.003 Pb.)
4	9.12 Al	
5	18.66 Al	
6	1.54 Zn	
7	3.28 Zn	
8	3.94 Pb	(0.14 Mn)
9	3.78 Sn	(0.010 Mn)
10	3.86 In	
11	3.94 Ti	(0.015 Mn.)
12	2.38 Ga	(0.015 Mn.)
13	4.18 Co	(0.002 Pb)
14	3.83 Ag	(0.015 Mn, 0.002 Pb)
15	—	0.21 Si (0.007 Fe, 0.08 Mn)
16	—	0.006 Fe (0.10 Mn, 0.004 Pb)
17	—	0.49 Ni (0.03 Mn, 0.004 Pb)
18	—	0.24 Ce (0.32 La, 0.032 Fe, 0.04 Mn, 0.016 Pb)
19	—	0.03 Ca (0.044 Mn, 0.003 Pb)
20	—	(0.023 Pb)
21	4.14 Mn	0.23 Cu (0.001 Fe, 0.032 Mn)
22	—	
23	—	

* Unintended Elements in Parentheses.

composition of the various alloys is given in Table I. Sheet stock was made by hot-rolling the scalped ingots in successive reductions of 10% with intermediate annealing at 350° C. Pure magnesium and alloy samples, approximately $\frac{1}{2} \times 1 \times \frac{1}{2}$ in., were made both from cast material and from rolled sheet stock, and the surface finish of the samples was standardised.

Experiments were carried out to determine the oxidation rate of rolled pure magnesium in pure oxygen at 503° 526° 551° and 575° C., the effect of temperature on the oxidation in various atmospheres, and the change of oxidation rate with an aluminium content varying from 0 to 18% at temperatures varying from 400° to 525° C. The effect of temperature upon the oxidation rates of the various magnesium alloys was also investigated. The effect of various gases and gas mixtures at atmospheric pressure upon pure magnesium was also determined at 550° C. The nature of the oxidation products obtained was studied through the application of macroscopic, optical and electron microscopic, X-ray and electron

diffraction and spectrographic methods

From the various results the linear oxidation of pure magnesium and of the series of magnesium alloys was measured within the temperature range 412° to 575° C. where a loose oxide scale forms. It was found that the logarithm of the rate was directly proportional to the reciprocal of the absolute temperature. The energy of activation for the oxidation of magnesium in this range was 50,500 cal. and the action constant was 6.2×10^{12} mg. per sq. cm. per hr. Alloying increased the rate of oxidation of magnesium whenever the melting temperature was significantly depressed by the alloying element. Magnesium formed a protective oxide film at low temperatures, a non-protective loose scale at higher temperatures, and might undergo combustion at temperatures approaching the melting point.

A theory of the oxidation of magnesium has been proposed. It is suggested that at low temperatures, and in the early stages of oxidation at higher temperatures, normal protective oxidation occurs, and when the protective scale reaches a critical thickness it disintegrates spontaneously and a linear zero-order reaction between oxygen gas and magnesium thereafter occurs at or adjacent to the metal surface. At still higher temperatures the rate of evaporation of magnesium becomes so great that the reaction occurs at a considerable distance from the surface and constitutes normal combustion with a flame.

Spark and Arc Circuits for Spectrographic Analysis

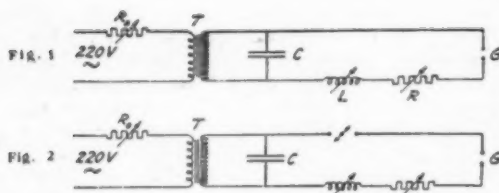
By C. GEORG CARLSSON and ROLAND RYNNINGER

A SURVEY is given of different electrical circuits used at present for spectrographic analysis. A first group consists of the self igniting (high-tension) spark. This can be of the uncontrolled type (free spark) (Fig. 1), or controlled by means of either a rotating interrupter (Fig. 2) or an auxiliary spark gap (tandem spark) preferably with a large inductance or resistance across the analysis gap.

It is pointed out that in the first case the energy of each spark is not affected by variations in the width of the analysis gap, in the second case by variation in the voltage of the mains but that in the third case the energy of

From *Metals Technology*, 1946, 13, No. 4, and *A.I.U.M.E. Tech. Public.*, No. 2003, pp. 1-28.

From *Jernk. Annal.*, 1947, 131, 1-23.



each spark is not affected by these factors.

A second group of light-sources consists of sparks produced by discharging a condenser charged to a voltage lower than the break-down voltage of the analysis gap, the discharge being triggered by a superposed high tension spark of low energy. An attempt is made to compare the different light-sources with regard to the characteristics of the single spark—i.e., essentially its frequency and damping, which together determine the time of action of each spark, and the initial current, which is of importance for the character of the spectrum excited (arc- or spark-like). It is

shown that with the triggered discharge sparks similar to those of the self-igniting type may be obtained as well as discharges giving spectra of the same kind as a direct current arc and, in addition to this, different intermediate forms. In the first case the voltage must be comparatively high, 5–10 kV, and the condenser small, in the second case the condenser must be large. With an indefinitely large condenser, which is equal to the direct current mains, one gets a direct current arc. Thus this old light source appears as a special case of the triggered spark. The triggered spark is extremely versatile and will probably be much used in the future.

A short description of a source-unit called "Emitator," comprising all the above-mentioned circuits, which is being manufactured in Sweden, is also included.

and the interdendritic beta constituent. This tearing occurs due to the inability of the beta constituent to withstand the tension stresses set up by the contraction of the solid metal on cooling after the liquid to metal solidification has been completed, and this differential contraction partly explains the reason that microporosity always occurs between the primary dendrites. Since zinc promotes hot-shortness, the tendency towards microporosity is increased by any mechanism, such as coring, whereby the zinc is concentrated in the interdendritic constituent of a two phase alloy, particularly if differential contraction can occur.

Microporosity can be minimised by the choice of a suitable alloy. Dowmetal C has been found to be less porous than Dowmetal H. when produced by similar foundry procedures. The two alloys form both alpha and beta constituents but the zinc content of the former is lower than that of the latter and there is less tendency towards hot-shortness of the interdendritic constituent in the C alloy.

X-ray tests were made on both alloys to determine the amount of porosity on the basis of the amount of illumination required to make the porosity just visible to the naked eye. The results of these tests are given in Tables 1 and 2 together with the corresponding yield points, tensile and fatigue strengths and elongations of the alloys. In those tables light porosity signifies the smallest amount that can be picked up by X-rays, fairly heavy porosity indicates the maximum amount which is generally found in castings made under good foundry conditions, and very heavy porosity the maximum amount which is ever found in magnesium alloy castings, even when made under poor foundry conditions.

Microporosity of Magnesium Alloy Castings

By H. Dobkin

CERTAIN commercial magnesium alloy castings, particularly those containing zinc, are prone to a type of defect known as microporosity. The porous areas consist of interdendritic cavities and are not visible to the naked eye and often not detectable by X-ray inspection, unless present in appreciable amounts. If present in small, widely segregated areas, microporosity does not affect the strength of the alloy. The strength is impaired by porosity only in large concentrated amounts, and, as microporosity can be segregated to low stressed areas of the casting by proper foundry technique, decreased strength is not an objection to its presence.

Microporosity is interesting from a metallurgical point of view, since the exact reasons for its occurrence are not known. Several theories have been proposed, each of which has its supporters, and each of which helps partially to explain the phenomenon. The first theory holds that microporosity is caused by microshrinkage, due to the failure to feed adequately the casting during the final stages of solidification.

The second theory is that microporosity is caused by the difference in solid solubility of the dissolved con-

TABLE II.—EFFECTS OF MICROPOROSITY ON FATIGUE STRENGTH OF MAGNESIUM ALLOY CASTINGS.

Alloy	Condition	Degree of Porosity	Endurance Limit Tons per sq. in.
Dowmetal C	Solution Treated	None	6-25
		Light	4-45
		Fairly Heavy . .	3-35
		Very Heavy . .	2-40

stituents at various temperatures. Since solid solubility of the alloying constituents is an inherent characteristic, any defects occasioned by it are difficult to overcome.

The third, and probably the most widely accepted theory, is that microporosity is caused by tearing along the interface of the alpha solid solution

TABLE I.—EFFECT OF MICROPOROSITY ON MECHANICAL PROPERTIES OF MAGNESIUM ALLOY CASTINGS.

Alloy	Composition			Condition	Degree of Porosity	Yield Point Tons per sq. in.	Ultimate Stress Tons per sq. in.	Elongation %
	Al	Mn	Zn					
Dowmetal H	5-3 6-7	0-15 min.	2-5 3-5	As Cast	None	6-25	12-05	5
					Light	6-10	11-90	4
					Fairly Heavy . .	5-75	10-55	2
					Very Heavy . .	3-30	8-20	1
				Solution Treated	None	6-25	17-40	12
					Light	6-05	16-70	6-5
					Fairly Heavy . .	5-90	11-75	4-5
					Very Heavy . .	3-30	9-60	2
Dowmetal C	8-3 9-7	0-10 min.	1-7 2-3	As Cast	None	7-15	10-70	2
					Light	6-50	8-50	0-5
					Fairly Heavy . .	6-10	7-90	0-5
					Very Heavy . .	3-70	7-15	0-5
				Solution Treated	None	7-15	17-40	10
					Light	6-50	13-10	3-5
					Fairly Heavy . .	6-70	11-90	2
					Very Heavy . .	6-10	8-45	1-5

From *The Foundry*, 1946, Vol. 74, No. 9, pp. 98-101, 178, 180, 182.

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